INCORPORATING NUTRIENT VARIABLES IN FOOD DEMAND ANALYSIS

By

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Dedicated to my parents

Mr. Tse-Shung Chung
&
Mrs. Bee-Ying Chiu

for their love and support

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The objective of this study is to investigate the impact of nutrients on consumers' food choice. Two different approaches are used in this study. The first approach is based on the traditional utility theory, or demand theory. In this approach, nutrient variables are assumed to affect consumers' utilities, which in turn affect food quantities consumed. A levels version of the Rotterdam model for a sub-demand system is derived and estimated. The second approach is based on the household production theory. Under the household production model, two optimization problems are involved. In the upper stage, food expenditure is assumed to be a function of food nutrients and the number of meals eaten and households are assumed to minimize their food expenditures subject to certain food preparation technology. In the lower stage, utility is assumed to be a function of nutrients consumed and household

composition; and the household is assumed to maximize it utility subject to a budget constraint.

Data reported in the 1987-88 Nationwide Food Consumption Survey is used to estimate these two models. Five food groups and seven nutrients are analyzed. Results suggest that the sub-demand system analysis is promising. In the levels version of the Rotterdam model, results indicate that nutrients lower the perceived food prices and thus increase the food consumed for food groups of meats, vegetables and fruit, grains, and the other. Results from the household production model suggest that nutrients played an important role in household's purchases of its foods to secure the nutrients in at-home meals.

This study explores the roles of nutrients in the demand for food through the utility theory and the household production theory. Results from both approaches support the argument that nutrients play an important role in food demand patterns.

CHAPTER 1
INTRODUCTION

Consumers play the key role in linking the provision of food by the agricultural sector to the ultimate nutritional well-being of the population. As a food consumer, an individual's food choices and consumption behavior have important nutritional and economic outcomes that affect his/her health status individually and the viability of the food system collectively. In other words, consumers' food choices affect not only their health but also the state of economy, agricultural production and the balance of trade and employment in the food sector as well as the fortunes of many companies. The availability, accessibility and choice of foods needed to meet an adequate and safe diet and to promote health are key challenges of our food system today as evidence exists that consumers are slowly shifting their eating patterns toward more healthy diets.

An understanding of the factors that influence food choices -- including economic, social, psychological, and physiological factors -- is required to meet the need for a basic understanding of the mechanisms that cause individuals to choose and consume foods. Knowledge of how people make food choices, what factors influence consumer's demand for food, factors that make food available for those in need of assistance, the economics of farm to food retail distribution, and changing food markets are critically important to the development of effective agricultural and food policies assuring a safe, affordable, reliable and nutritious food supply and to the expansion of food markets for U.S. products in the United States and in the international market.

According to the U.S. Department of Agriculture (USDA, 1997), Americans spent about \$375 billion on food purchases (at-home) in 1996, an increase of about \$139 billion from 1985. However, the proportion of expenditure on food has fallen from about 20 to 12 percent in the United States during the last 20 years, while per capita real disposal real income has risen through time (Putnam, 1990). In the United States, nutrition practices have become popular measures to prevent almost all diseases. For example, a significant proportion of Americans have decreased their intake of red meat and cholesterol in response to warnings that excessive consumption of cholesterol is associated with coronary artery disease (Breidenstein, 1988). Other phenomena that reflect concern with preventive nutrition include increased sales of vitamin/mineral supplements and books that describe special "anti-disease" diets and consumers' heightened concern with product ingredients. Good nutrition is a key to obtaining optimal health and productivity and to reducing the risk for chronic and infectious diseases.

The ability to understand present as well as future patterns of food consumption is of great importance to policymakers such as the USDA, state and local agencies, and private commodity and industry groups. Changes in the economic, social and demographic environment, along with consumer knowledge and awareness of the health-promoting aspects of dietary choices, all influence consumers' demand for food. In addition, changes proposed to a nation's welfare and food assistance programs are likely to directly affect the food choices and well-being of those in need of assistance. More effective public policies in the food sector will occur with improvement in the understanding of structural elements of food consumption and the factors that determine the adoption of a healthy diet.

The USDA classifies food into five groups: dairy products; meats and other protein foods; fruit; vegetables; and grain (1992). Given the evidences that consumers have changed their attitudes toward more healthy diet in terms of good nutrition, it is then assumed that consumers are equipped with the knowledge of which major nutrient ingredients are embodied in these five food groups, and of which food items comprise these five groups. For example, dairy products -- such as milk, cheese, and yogurt -- are important sources of protein, calcium, riboflavin, and other nutrients; meats and other protein foods provide protein, iron, and zinc; vegetables and fruits provide variable amounts of vitamins, minerals, and fiber; and grains -- including breads, cereals, rice, and pasta (that is, all foods from grains) -- are good sources of carbohydrates, fiber, vitamins, and minerals.

The Dietary Guidelines (HHS/USDA, 1995) and Food Guide Pyramid (USDA, 1992) recommend the selection of foods from a variety of food groups, the choice of a diet that is low in fat, saturated fat, and cholesterol, and moderate in the use of salt and sodium. In an effort to measure how well American diets conform to recommended healthy eating patterns, the USDA (CNPP/1995) has developed the Healthy Eating Index. The findings from this index indicate that, in general, the American diet does not meet these recommendations but is high in total fat and saturated fat and low in fiber and complex carbohydrates. Less than one-third of individuals in this study consumed the recommended servings of milk and meat, while fewer than one out of five individuals consumed the recommended servings of grains, vegetables, and fruit.

Food consumption and the accompanying nutritional quality of the diet are determined by income and prices as well as a broad range of other factors. Changing demographics and household composition, women's labor force participation, new concerns about health-diet

links and food assistance programs, and changes in the food markets all affect the types and amount of food that are consumed. According to a recent survey by the Food Marketing Institute (1993), consumers seem to be very concerned with the health-related issue of nutrition. At least nine out of 10 respondents have changed their eating habits to ensure a healthy diet. For at least the last five years before this survey was conducted, the consumption of more fruit and vegetables has been the primary way that shoppers ensured themselves of a healthful diet (59 and 62 percent in 1989 and 1993, respectively). This behavior was reported more than twice as often as any other dietary behavior in terms of means toward a healthy diet. Three out of 10 shoppers either ate less meat or less red meat (30 percent) or consumed less fats and oils (26 percent). Food selection differs among shopper subgroups. That is, more women than men considered nutrition important (83 versus 53 percent), and the importance of nutrition to consumers increased with age. In short, there is a trend toward buying foods with low fat, less salt, less sugar, more vitamin/mineral, and more nutritional value.

Food selection, market purchase, and food preparation decisions are critical determinants of diet-related health concerns for consumers as well as factors that affect the structure and composition of the food supply. Good information on behavioral relationships that determine food choice is critical in designing effective food assistance programs and in developing insights regarding future food consumption patterns.

Given the facts that the American diet does not appear to meet the recommended requirement (CNPP/USDA, 1995) and that there is a trend toward more healthy diets, the objective of this study is to analyze the effects of economic factors on food demand and consumption behavior by identifying and estimating the linkages of nutrition knowledge by

household or consumer food choices; that is, the objective is to investigate the role and effects of nutrients in consumers' or households' food consumption patterns. Furthermore, health-related public policy on nutritional quality, health, food consumption and prices, and promotional activity programs, such as advertising sponsored by the food industry, can be evaluated or designed based upon the findings of this study.

It is well-known that nutritional attributes are often the major themes in the advertising of various commodity groups. Florida orange juice is claimed for its richness in folate and vitamin C; milk is rich in calcium, for example, "milk does a body good"; and pork is relatively lean, has less cholesterol than it previously had, and is advertised as "the other white meat." All these promotional activities are intended to change consumers' perceptions and awareness of nutritional content in food commodities in question so that consumers will increase their consumption of the respective food commodities.

Two different approaches are developed to examine household food consumption behavior in this study. Both approaches are constructed in a demand subsystem. First, because more nutritious food is assumed to increase a household's utility function, a levels version of the Rotterdam model, extended with the nutrient variables, is developed. This approach not only allows the calculation of price and expenditure elasticities of demand for selected food groups but also allows one to capture the impacts of food group-specific nutrients on the demand for these food groups. In other words, a representative consumer or household's utility is assumed to be a function of the quantities of food consumed and the nutrient contents of food, where the individual nutrient variables are food group-specific.

In the second approach, households are assumed to demand food attributes or nutrients embodied in various foods and the number of meals eaten at home using the

household production theory. This household production model allows researchers to estimate the price and expenditure elasticities of nutrients. Although these two models are different in assumptions, their common objective is the same -- to analyze the effects of nutrients on food demand.

This study is comprised of five chapters. In chapter 2, a review of existing literature related to nutrition on consumer food demand is presented. The specification of the extended levels version of the Rotterdam model, methods of estimation, data, sources of nutrients, and the estimation results are provided in chapter 3. In chapter 4, the specification of the household production model, data, and the estimation results are presented. Finally, in chapter 5, a summary, concluding remarks, and implications are provided.

CHAPTER 2
LITERATURE REVIEW AND APPROACHES

This chapter consists of three sections. The first section presents a brief overview of determinants of food demand choice. A literature review of studies that incorporated nutrient variables into food demand analyses is then provided. In the last section, two approaches used in this study are presented.

Determinants of Food Demand Choice

Most of the early work in understanding factors affecting food selection focused on the food items themselves -- taste, texture, other sensory components, and the overall acceptability of the food (Kare and Maller, 1967 and 1977). More recently, studies in the food choice arena have suggested that factors other than food -- including social factors (with whom a consumer is eating or purchasing (deCastro and deCastro, 1989)), temporal factors (at what time or the time available for a consumer to eat or purchase (Birch et al., 1984)) and environmental factors (the physical surroundings) -- are instrumental in guiding food choices and should be the focus of more research (Meiselman et al., 1988; Meiselman, 1992; Rozin and Tuorila, 1993).

Pelto's (1981) definitions of factors influencing food choice differ somewhat from the studies from above; however, the basic underlying mechanisms of food selection are the same. According to Pelto, both the social-economic-political system (or social factors) and the food production and distribution system (or environmental factors such as food availability, and food marketing channels, ... etc.) affect lifestyle factors such as income, occupation, education,

ethnic identity, rural-urban residence, religious belief, health, nutrition knowledge, and physiological characteristics, and then affect individual lifestyle, and finally affect food choice behaviors.

Convenience is a newly rising factor that affects consumer food choice behaviors in addition to those factors stated above. "Time will be the currency of the nineties," according to a report of the US Institute of Economists. U.S. surveys reveal that the most prized inventions are those such as the microwave, remote control electronic devices, and automatic coffee makers, which empowered consumers and freed up time that they could subsequently control and use (Senauer et al., 1991). With the increasing importance and value of time resources comes a greater demand for convenience in food, along with other goods and services, although this can create conflict with the other major trend in food habits, that of healthy eating (Bull, 1985; Carruthers, 1988). In the United States, for example, poultry consumption (of which 80 percent is chicken) rose from 19 percent of total meat poultry and fish consumption in 1966 to 32 percent in 1989. However, 40-45 percent of all chicken consumed is purchased in fast-food stores, primarily in the form of fried chicken.

The issue between health and diet has drawn more and more attention by consumers. Table 2-1 shows a survey result made by the Food Marketing Institute (1993): 98, 97, 96, and 91 percent of the respondents showed concerns about taste, the nutritional contents of foods, price, and product safety, respectively. Seventy-nine and 75 percent of respondents indicated that "ease of preparation" and "food preparation time", respectively, were very or somewhat important. Taste was by far the most important consideration in selecting food, with nine out of 10 shoppers indicating that taste is very important. It outweighs nutrition (75 percent), price (74 percent), and product safety (72 percent). In a study involving married couples,

Table 2-1. Importance of Various Factors in Food Selection, 1993.

Factors	Very Important (1)	Somewhat Important (2)	Total (1) + (2)
Taste	91	7	98
Nutrition	75	22	97
Price	74	22	96
Product Safety	72	19	91
Storability	45	37	82
Product Packing That Can Be Recycled	41	37	78
Ease of Preparation	37	42	79
Food Preparation Time	36	39	75

Source: Food Marketing Institute (1993).

Schager (1978) found that husbands rated taste, followed by nutrition, the most important determinant of food choice, while the wives rated nutrition followed by taste as being most important. McNutt et al. (1986) found taste, following safety, to be the most important factor. However, when one begins to examine indices of buying behavior, it is equally clear to the researcher that taste is not the only crucial determinant and in some cases clearly falls well down the priority list (Raats et al., 1995).

A study by the Food Marketing Institute (1993) found that, for the period from January 1989 to January of 1993, more than 90 percent of respondents had adjusted their diets for health or nutrition reasons. Respondents were concerned about the intakes for particular nutrients, especially fats and cholesterol (Borra, 1988). These studies found that nutritional contents are important factors in the demand for food. Until recently, most food demand studies assumed that the demand for food or food subgroups was only a function of prices and budget. The deliberate or unintentional ignorance of such nontraditional variables, nutritional contents, may result in biased estimation of structural demand relationships. To quote Manderscheid (1964):

> In both experimental and nonexperimental studies uncontrolled variables may, if they are important, affect the relationships being studied. A study of the relationship between skim and whole milk prices at retail might be upset by a "cholesterol scare" if such a scare received widespread public attention and if the experimental design or statistical procedure did not remove its effect.

The major purpose of this study is to empirically estimate the sensitivity of the demand for several categories of foods to changes in prices, food expenditure, and the nutritional contents of these foods. The demand system approach will be utilized along with multistage budgeting.

Literature Review

A few studies have incorporated nutrient variables into the food demand analyses. Some have used a cholesterol information index -- a measure of the number of medical journal articles that disseminate cholesterol in relation to heart disease -- as a variable in demand equations (Brown and Schrader, 1990; Capps and Schmitz, 1991; Chang and Kinnucan, 1991). Other have considered demand equations for specific nutrients as functions of income and sociodemographic variables based upon household survey data (Adrian and Daniel, 1976; Akin, Guilkey, and Popkin, 1983; Basiotis et al., 1983; Chavas and Keplinger, 1983; Devaney and Fraker, 1989; Scearce and Jensen, 1979). Some studies have proposed a formula to calculate nutrient elasticities for use in measuring price and income effects on nutrient availability (Gould, Cox, and Perali, 1991; Pitt, 1983; Sahn, 1988). A recent study by Huang (1996) explored the linkage between the determinants of food choice and consumer nutrient availability using Lancaster's linear characteristic model. (Note that Gorman (1956) developed the linear characteristic model, and Lancaster (1966 & 1971) extensively discussed it.) Huang also provided the derivation of nutrient elasticities.

This literature review attempts to integrate and summarize diverse demand analysis studies that agricultural economists have conducted in conjunction with the issue of health and nutrition. This literature can be classified into four categories: (1) assessment of the effect of attitudes and information about health and nutrition on the demand for food products; (2) determination of demand for specific nutrients; (3) construction of hedonic price or consumer goods characteristics models for nutrients; and (4) incorporation of nutrient variables into a food demand system.

Attitudes and Information About Health and Nutrition

According to national consumer attitudinal research, consumers seem to prefer leaner beef (Yankelovich, Skelly, and White, 1985). A few studies have been conducted to examine consumer attitudes and preferences toward beef. Branson et al. (1986) examined the effects of various degrees of leanness on consumer demand. Skaggs et al. (1987) and Menkhaus et al. (1988) analyzed the potential performance of marketing branded, low-fat, fresh beef. The common results of these studies are: (a) consumers appear to be concerned about health in regard to the ingestion of animal fats; (b) consumers are willing to compromise taste for a product that is perceived to be more healthy; and (c) health-related factors affect the decision to purchase leaner meats. A study conducted by Decision Center, Inc. (1987) for the American Meat Institute examined the awareness and usage of branded lean beef supplied by Giant Foods, Inc., a chain located in the Baltimore-Washington area. This particular brand is found to be popular with female customers who are employed, are under the age of 40, have children, and are concerned with the issue of health and nutrition. Capps, Moen, and Branson (1988) examined consumers' willingness to try lean meat products from a retail food chain in Houston. Using survey data collected through telephone calls and a probit model analysis, Capps, Moen, and Branson found that fat-conscious consumers (consumers with a preference toward buying low-fat foods) are more likely to try lean meat products than nonfat-conscious consumers (consumers without preference toward buying low-fat foods) empirically, *ceteris paribus*.

Several studies incorporated attitudinal variables and information about health and nutrition in demand analysis. The role of nutrition and health information has been the subject of several studies of consumer food choices. For instance, Stokes and Haddock (1972) found

that exploration and instructions pertaining to the use of nutrition information increase consumption toward "nutritious" food. Schutz, Judge, and Gentry (1986) focused on the importance of nutrition, brand, and sensory attributes to the purchases of several foods.

Pulter (1987) as well as Brown and Schrader (1990) examined the effect of cholesterol information on shell egg consumption. Pulter (1987) modeled the effects of cholesterol information in a demand relationship for eggs via a nonlinear time specification that corresponded to a diffusion process. Pulter argued that health information is unlikely to be received by all consumers instantaneously; instead, the health information diffuses through the population over time.

Brown and Schrader (1990) constructed a cholesterol information index to estimate the effect of cholesterol information on egg consumption. This index is a running total of the number of articles available to the medical profession. Each article supporting the linkage between cholesterol and heart disease adds one unit to the running total (lagged two quarters), and each article rejecting the linkage reduces that total by one unit. The underlying hypothesis in their study is that consumers' attitudes toward cholesterol changed slowly as scientific information accumulated, so a lagged index based on the number of articles in medical journals could serve as a proxy for information perceived by consumers from many sources. Using quarterly time-series data from 1955 I to 1987 II, Brown and Schrader augmented the standard Marshallian demand relationship for eggs by including the cholesterol information index. Two general equilibrium models were used to determine whether cholesterol index is an important factor affecting shell egg consumption; one is a constant-coefficient model, and the other is a changing-coefficient model (price and income coefficients are assumed to vary with cholesterol index). Adjustments were also made for seasonality and the percentage of

women in the labor force. For the constant-coefficient model, all three structure variables (cholesterol information index, percentage of women in the labor force, and timing) were suggested to be included. For the changing-coefficient model, the positive coefficient on the interaction of egg price and cholesterol index indicates a decrease in the price elasticity for shell eggs, which in turn implies that egg consumption increased less than would have been the case without cholesterol information as real prices for eggs dropped. The negative interaction of income and the cholesterol information index also indicates a decrease in the income elasticity for eggs, which means that egg consumption increased less than would have been the case without the cholesterol information as income increased. Therefore, results under both models in their study suggested that information on the links between cholesterol and heart disease decreased per capita shell egg consumption.

In order to investigate demand interrelationships among meat products, Capps and Schmitz (1991) used a demand system approach. Capp and Schmitz adopted the cholesterol information index developed by Brown and Schrader (1990) and assumed health and nutrition information as an argument in the utility function affecting the quantity variables (Basmann, 1956; Lancaster, 1966), that is,

$$u_t = u(q_t; \theta(\gamma_t)), \tag{2.1}$$

where $\theta(\gamma_t)$ describes the impacts of γ_t on consumer preferences for the commodity vector, q_i. The vector, γ_t, consists of scientific information pertaining to cholesterol, sodium, dietary fiber, or saturated fats, etc. The key assumption in Capp and Schmitzs' study is that changes in scientific information about health and nutrition factors (γ) in time *t* result in changes in the vector of commodity quantities consumed, q_t, which in turn gives rise to changes in the

parameters of the utility function. In other words, under this assumption, the formulation of consumer preferences can be considered in part on information about the characteristics of commodities. However, the utility function should be described as $u(q_t(\gamma_t))$, the utility function (2.1) is not consistent with the assumption as Capp and Schmitz claimed.

Capps and Schmitz then introduced the information of health and nutrition -- cholesterol information index, into the Rotterdam demand model, which is

$$\begin{aligned}
&w_{it}^{*}Dq_{it} = \Upsilon_i \ln(CHOL_{t-1}) + b_i[Dy_t - \sum_k w_{kt}^{*}Dp_{kt}] + \sum_j c_{ij}Dp_{jt} + \epsilon_{it}, \\
&\text{where} \\
&Dq_{it} = \ln[q_{it}/q_{i,t-1}], \\
&Dp_{kt} = \ln[p_{kt}/p_{k,t-1}], \\
&Dy_t = \ln[y_t/y_{t-1}], \\
&w_{it}^{*} = (w_{it} + w_{i,t-1})/2.
\end{aligned} \tag{2.2}$$

q_{it} and p_{it} correspond to price and quantity consumed in period *t* for the the *i*th commodity; y_t is the *t*th period's total expenditure or income; and $CHOL_{t-1}$ corresponds to the cholesterol information index developed by Brown and Schrader (1990). The symmetry and homogeneity conditions are the same as those in the traditional specification; in addition, there is an extra constraint to the adding-up condition, namely $\sum_i \Upsilon_i = 0$. Capp and Schmitz reported that there is evidence that cholesterol information, with a half-year lag, is an important determinant in the consumption of pork, poultry, and fish. However, the way that health information was incorporated in the demand model (2.2) is ad hoc because Capp and Schmitz did not show the derivation of the first term on the right-hand side (RHS), $\Upsilon_i \ln(CHOL_{t-1})$, nor did they explain how the health information $CHOL_{t-1}$ comes into play in this model. The addition, $\Upsilon_i \ln(CHOL_{t-1})$, is inconsistent with the spirit of the Rotterdam model; that is, variables should be defined as logarithmic differences.

Chang and Kinnucan (1990) examined the impact of cholesterol information on the consumption of fats and oils in Canada. A cholesterol information index served as a proxy for increasing consumer awareness of cholesterol as was the case in Brown and Schrader (1990) and Capps and Schmitz (1991). An "effective publicity" measure for the cholesterol information index was developed in contrast to Brown and Schrader's (1990) "net publicity" measure. The "effective publicity" measure, rather than the net negative information in the "net publicity" measure, was constructed in the way that weighted negative information plays a role in formulating the information index,.

Chang and Kinnucan (1991) approached the consumer choice problem by assuming that consumers' perception of the quality (Z) of a good (X) affects the satisfaction or utility in consuming the good (Swartz and Strand, 1981; Brown and Schrader, 1990). Furthermore, a consumer's perception of product quality will depend on the information ($INFO_t$) that a consumer has about product attributes in period t. Thus, the utility function can be written as

$$u = u(X(Z(INFO))). \tag{2.3}$$

Moreover, weakly separable utility was assumed and then multiple-stage maximization followed; the utility function (2.3) can be partitioned into several subutilities with each corresponding to its respective commodity or group of commodities. Under this framework, multiple-stage budgeting is made possible, for example, a consumer decides first on his total consumption of food, then on the budget among food groups, and finally on the allocation among individual commodities within a particular food group.

The estimated equation Chang and Kinnucan employed is

$$Q_{i,t} = \alpha_i + \sum_j \alpha_j \ln P_{j,t} + \beta_i \ln(TEXP_t / P_t^*) + \eta_i \ln INFO_t + \sum_k c_k D_k + \xi_{i,t}, \tag{2.4}$$

where $Q_{i,t}$ is per capita consumption of good *i* in quarter *t*; $P_{j,t}$ is the real price of good *j* in quarter *t*; $TEXP_t$ is the consumer's total group expenditure on fats and oils in quarter *t*, deflated by the Stone price index, $P_t^* = \sum_j w_{j,t} \ln p_{j,t}$; $w_{j,t}$ is the budget share of good *j* in the fats and oils group in quarter *t*; $p_{j,t}$ is the nominal price of good *j* in quarter *t*; $INFO_t$ is consumer information on cholesterol received in quarter *t*; D_ks are seasonal dummy variables; and $\xi_{i,t}$s are random error terms.

There are no demand restrictions imposed on the estimation. The estimated coefficients of the cholesterol information index are significant in the butter and salad oil equations. The negative coefficient for butter indicates that the demand for butter decreases as scientific knowledge about the role of cholesterol in heart disease increases, *ceteris paribus*, while the positive coefficient for salad oil suggests that the demand for salad oils increases as the information about cholesterol increases. Results also suggested that commodity promotion strategies by the industry might be effective to some degree in terms of providing positive information against negative information. These findings are indeed consistent with the notion that saturated fats (a major ingredient in butter) are unhealthy, while unsaturated fats (contained in specific salad oils) are relatively better in terms of health.

Gould, Cox, and Perali (1991) estimated U.S. food fats and oils demand using quarterly disappearance time-series data for the period 1962-87 and an almost ideal demand system (AIDS) model with demographic scaling specification. In their study, demand was expressed as a function of prices, expenditure, and demographic variables; that is,

$$D_i = D_i(\mathbf{P}, S, M), \quad i = 1, \ldots, n. \tag{2.5}$$

The scaling specification assumes that the scaling parameters are functions of the demographic variables; that is,

$$\phi_i = \phi_i(s_1,\ldots,s_d), \tag{2.6}$$

and therefore allows the effects of demographic variables to influence fat and oil prices by modifying the demand system as

$$\begin{aligned} D_i(P,S,M,) &= \phi_i D_i^*(p_1\phi_1, p_2\phi_2,\ldots,p_n\phi_n,M) \\ &= \phi_i D_i^*(p_1^*, p_2^*,\ldots,p_n^*,M), \end{aligned} \tag{2.7}$$

where $S = [s_1,\ldots,s_d]$ and $p_i^* = \phi_i p_i$ are scaled prices.

The results indicate that the model specification with demographic scaling fits the data quite well statistically, which suggests that the system-wide approach to demand analysis is more appropriate, particularly when household level cross-sectional data are used. In addition to the price, income, and demographic demand elasticities, the implied dietary fat intake elasticities are calculated for each of the demographic characteristics. Gould, Cox, and Perali concluded that older consumers revealed strong preferences for butter (and vegetable shortening) prior to current concerns for cholesterol and saturated fat in the U.S. diet, which is again consistent with the notion that consumption of saturated fat -- a main ingredient contained in butter -- could jeopardize health. This result is similar to the findings reported by Chang and Kinnucan (1991).

Demand for Specific Nutrients

Knowledge of factors that influence nutrient demands is useful in the design and implementation of programs to promote improvements in nutrition and in the modification of current programs -- such as Food Stamp Program (FSP); National School Lunch Program (NSLP); Special Supplemental Food Program for Women, Infants, and Children (WIC); and National School Breakfast Program (NSBP) -- to make them more effective and efficient.

Most of these government programs are designed to improve the nutritional status of children, particularly those whose incomes fall below poverty level.

A typical model of demand for specific nutrients resembles the Engel function, which can be represented by

$$N_{hi} = \varsigma_h + \tau_h m_i + \omega_{h1} A_{1i} + \ldots + \omega_{hn} A_{ni} + \Gamma_{h1} B_{1i} + \ldots + \Gamma_{hf} B_{fi}, \tag{2.8}$$

where N_{hi} denotes the intake of nutrient *h* by the *i*th economic agent (individual or household); m_i is income for the *i*th agent; $A_{1i}, \ldots, A_{n1}$ constitute a set of binary variables that denote participation in various government programs by the *i*th economic agent; and $B_{1i}, \ldots, B_{fi}$ represent a set of sociodemographic variables. Model (2.8), in fact, resembles an allocation model that allocates the food budget (or income) among various foods. Since nutrients are parts of foods, factors affecting food consumption also affects the consumption of specific nutrient.

Cross-sectional data sets are usually used for this type of study. In most cases, evidence exists to indicate that participation in government food assistance programs leads to increases in the levels of nutrient intakes, *ceteris paribus* (Akin, Guilkey, and Popkin, 1983; Basiotis et al., 1983; Chavas and Keplinger, 1983; Scearce and Jensen, 1979). The sociodemographic variables most commonly used in the models are income, education, household size, ethnicity, and urbanization. In many instances, the effects of the respective sociodemographic factors on nutrient levels are statistically significant, *ceteris paribus*. However, the impact of sociodemographic factors varies across samples and model specifications.

In Table 2-2, selected studies represented by equation (2.8) are summarized in terms of the data set used, types of nutrients concerned, food programs in question, and

Table 2-2. Selected Studies Pertaining to the Demand for Specific Nutrients Specified as Equation (2.8).

Researcher(s)	Data Set	Nutrients Considered	Food Programs Considered	Sociodemographic Variables Considered
Adrian & Daniel	1965-66 NFCS	PR, CAR, FT, Vit A, Vit C, CAL, IN, TH	None	Education, Employment Status, Household Size & Life-cycle Stage, Meal Adjustment, Race, Urbanization
Akin, Guilkey, & Popkin	1977-78 NFCS	FE, IN, Vit A, Vit B-6, Vit C	NSLP	Gender of Household Head, Ethnicity, Education & Hours Worked (Mother's), Household Size, Parenting Status, Race, Urbanization
Basiotis et al.	1977-78 NFCS Low Income (NFCS-LI)	FE, PR, CAL, IN, RB, TH, Vit A, Vit C	FSP	Ethnicity, Household Size & Composition, Region, Urbanization
Chavas & Keplinger	1977-78 NFCS, Two Spring Quarters	FE, PR, CAL, IN, PH, NC, TH, RB, Vit A, Vit B-6, Vit B-12, Vit C	FSP, NSLP, NSBP, GMSE, WIC	Education, Household Size, Ethnicity, Race, Region
Devaney & Fraker	1980-81 Cross-sectional Survey of Students, 1980-81 Household Survey of Parents, in 1st Part of National Evaluation of School Nutrition Program	FE, CAL, IN, MG, Chol, Vit A, Vit B-6	NSBP	Education, Ethnicity, Employment Status, Household Size, Race, Region, Urbanization
Scearce & Jensen	1972-73 BLS, CES	FE. PR, CAL, IN, NC, Vit A, Vit B-1, Vit B-12	FSP	Education, Family Life-cycle Status, Household Size, Race, Urbanization

NFCS is National Food Consumption Survey; BLS is Bureau of Labor Statistics; CES is Consumer Expenditure Survey.

CAL = Calcium; Chol = Cholesterol; FE = Food Energy; FT = Fat; IN = Iron; NC = Niacin; MG = Magnesium; PH = Phosphorus; PR = Protein; RB = Riboflavin; TH = Thiamin; Vit = Vitamin.

FSP = Food Stamp Program; NSBP = National School Breakfast Program; NSLP = National School Lunch Program; GMSE = Group Meal Service for the Elderly; WIC = Special Supplemental Food Program for Women, Infants, and Children Program.

This table is expanded based upon Capp and Schmitz's (1991) study.

sociodemographic variables considered. Given that household income variable is already represented by $\mathbf{m}_i$ in equation (2.8), it is therefore not listed under the last column in Table 2-2 even though it was considered a sociodemographic variable in all selected studies. The demand model (2.8) is usually employed to predict the nutrient intakes for economic agents with given economic and sociodemographic variables. In addition, the construction of the models allows analyses not only of the impacts of various government programs but also of sociodemographic factors on levels of nutrient intakes.

Considerable literature has been written on links between income and nutritional status. The effectiveness of income transfers in the alleviation of nutritional deficiencies varies across countries. Timmer and Alderman (1979) employed household budget data from Indonesia to investigate the determinants of demand for calorie intakes in order to generate food policy recommendations. They recommended that income redistribution might improve the nutritional status of the population given constant prices. Similarly, Pinstrup-Anderson and Caicedos' (1978) study of household survey data form Cali, Colombia, suggested that income redistribution might increase the demand for calories and protein for low income households. Via a two-stage estimation using household survey data from Sri Lanka, Sahn (1988) investigated food consumption patterns by estimating price and income parameters. He also reached the conclusion that the redistribution of income is the most important factor in determining the degree of calorie adequacy in Sri Lanka. Adrian and Daniel (1976) studied nutrient consumption in the United States, where a far larger proportion of the population has higher incomes. Using the data from the 1965-66 NFCS, Adrien and Daniel found that the consumption of nutrients by the U. S. population is not typically responsive to income.

Hedonic Price Models

For analyses related to nutrition issues, hedonic price and /or characteristics models are attractive because of their ability to impute the marginal values (shadow or implicit prices) of nutrients. A typical hedonic price model can be written as

$$p_i = \alpha_i + \sum_h b_{ih} N_{ih} + \varepsilon_i, \tag{2.9}$$

where b_{ih} is the marginal implicit price of the *h*th nutrient or dietary component, N_{ih} is the amount of nutrient or dietary attribute *h* associated with a unit of good *i*, and p_i is the price of good *i* (Cook and Eastwood, 1992; Eastwood, Brooker, and Terry, 1986; Huffman, 1988; Morgan, 1987; Morgan, Metzen, and Johnson, 1979). From equation (2.9), for each good consumed, the consumer pays the price equal to the sum of marginal monetary values of the characteristics of the good. Morgan, Metzen, and Johnson (1979) use this model to determine a set of hedonic prices for the nutritional attributes of breakfast cereals.

Cook and Eastwood (1992), Eastwood, Brooker, and Terry (1986); Ladd and Suvannunt (1976); Huffman (1988); and Capps (1987) used the hedonic price model to determine a set of shadow prices for five, seven, eight, 13, and 14 nutrients, respectively. The common ground for these five studies is that they all employ the 1977-78 NFCS data set; Cook and Eastwood; Huffman; and Eastwood, Brooker, and Terry used the spring portion of the survey, while Capps used all seasons from the survey. With this model, they were able to measure the shadow prices of nutrients.

Table 2-3 summarizes the estimated hedonic prices for various nutrients from the four studies mentioned above. The estimated shadow price for the removal of one gram of fat is 1.954 cents (0.968 cents) by Huffman (Capps), while it is 0.248 cents for the inclusion of one gram of fat by Eastwood, Brooker, and Terry. For protein, the shadow prices range from 0.44

Table 2-3. Hedonic Prices in Cents per Unit of Nutrients from Selected Studies Using the 1977-78 NFCS.

Nutrient	Cook & Eastwood[a]	Eastwood, Brooker, & Terry[a]	Huffman	Capps
Food Energy (¢/cal)	0.294**		0.052*	0.132*
Carbohydrate (¢/gm)		0.021*		-0.547*
Calcium (¢/gm)			-0.003	0.026*
Fats (¢/gm)		0.248*	-1.954*	-0.968*
Iron (¢/gm)			-0.285	-0.290*
Magnesium (¢/gm)			0.035*	0.102*
Niacin (¢/gm)			13.842*	2.933*
Phosphorus (¢/gm)			-0.068	-0.027*
Protein (¢/gm)		0.440*	0.439*	0.648*
Riboflavin (¢/gm)			-0.303	-9.913*
Thiamin (¢/gm)			-103.150*	-25.259*
Vitamin A (¢/IU)	-0.001**	-0.002*	-0.003	0.003*
Vitamin B6 (¢/mg)			-36.219*	-13.044*
Vitamin B12 (¢/mg)			8.230*	0.324*
Vitamin C (¢/mg)	0.128**	0.165*	0.365*	0.175*
Minerals (¢/mg)	0.021**	0.012*		
Vitamins B (¢/mg)	2.450**	2.335*		

a, Vitamin B includes niacin, riboflavin, thiamin, vitamins B6 and B12, while minerals contains calcium, iron, and magnesium; the estimates reported are for the middle subsistence group.

* Denotes that the parameter estimates are significantly different from zero at $\alpha = 0.01$ level, while ** indicates the estimates are significantly different from zero at $\alpha = 0.05$ level.

to 0.65 cents. For iron, the shadow price is 0.29 cents for the removal of one milligram. The estimates reported in the second column in Table 2-3 are based on the behavior of the middle subsistence group by Cook and Eastwood (1992). The middle subsistence group is defined as a group of households that meet the respective Thrifty Food Plan (TFP, Cleveland et al., 1983) subsistence levels for at least one nutrient. These results from Cook and Eastwood's study are similar to the findings by Eastwood, Brooker, and Terry (1986). Aside from that the subsistence levels of nutrients are incorporated in the demand functions of Cook and Eastwood's study, this is an expected outcome given the fact that both studies used the same hedonic price model. Table 2-3 also shows that little similarity exists when comparing results from these two studies to those of the other two studies; the exception is for, perhaps, protein and iron among the estimates of various nutrient characteristics. A reasonable explanation might be that different demographic variables were selected to estimate the demand function using the same or different data sets.

The incorporation of nutrients in demand analysis is not an easy task because of the fact that the representative consumer usually does not have the knowledge of the nutritional content of foods and that nutrients are not necessarily independent from one another. The main assumption -- that consumers care about the nutritional attributes or characteristics -- is required for this kind of demand analysis. To quote LaFrance (1983):

> even if consumers do not compute or calculate at the margin the values of obtaining an additional milligram of vitamin B_6, for example, they are undoubtedly aware of health and nutritional needs in general. Even if consumers are not fully aware of the actual levels of various nutrients in each food item, it remains a biological fact that certain vitamins, minerals, protein, carbohydrates, and fatty acids are essential to the continued survival and health of the human body.

In fact, the hedonic price model is a special case of the household production model. According to Deaton and Muellbauer (1980):

> Empirical work on quality corrected price indices is mostly based on a procedure referred to as the hedonic technique and this is usually justified in terms of household production theory. . . . Stone (1956), for example, used alcoholic content as a way of comparing prices of different alcoholic beverages. The empirical applications typically regress prices or the logs of prices of the different varieties of a type of good on such specification variables.

In essence, the hedonic price model expressed in equation (2.9) reflects that the quality of various foods is adjusted by the existence of their nutritional ingredients, and the quality change in the household production framework is treated as a change in household technology. The shadow prices of nutrients, b_{ih}s, can be estimated by (2.9). The demand for non-market outputs or nutrients can then be estimated as the shadow prices of these outputs are obtained, and the household's full cost minimization problem can be solved as a function of its utility, market input prices, and its capital stocks. This illustrates that the hedonic technique is justified in terms of household production theory.

Incorporation of Nutrient Variables in a Food Demand System

Since nutrient price elasticities summarize the net effect of food price changes on net nutrient intakes, knowledge of the complete matrix of nutrient price elasticities would be critically useful in designing nutrition-oriented food policy. It would be especially useful for countries whose national goals are set in terms of nutritional intake and where there is heavy intervention in the markets for foods.

Using a Tobit (Tobin, 1958) model, Pitt (1983) estimated food demand equations, given nutrient availability for households in rural Bangladesh, to generate a recommendations

for food policy. A Tobit model allows the positive probability of observing nonconsumption, which usually presents a problem when using household survey data. Using the linear characteristic model, Pitt derived uncompensated and compensated nutrient price elasticities and nutrient-expenditure elasticities. The linear characteristic model is

$$z_j = \sum_i b_{ji} q_i . \tag{2.10}$$

Model (2.10) means that one unit of each good, q_i, contains b_{ji} units of the non-market good *j* and that z_j is the total non-market good *j* contained in all goods considered. The derived uncompensated (ϕ_{nj}) and compensated (ϕ^{*}_{nj}) nutrient price elasticities and nutrient-expenditure elasticities are

$$\phi_{nj} = \frac{\sum_i a_{ni} \eta_{ij} E(y_i)}{\sum_i a_{ni} E(y_i)}, \tag{2.11}$$

$$\phi^{*}_{nj} = \frac{\sum_i a_{ni} \varepsilon_{ij} E(y_i)}{\sum_i a_{ni} E(y_i)}, \tag{2.12}$$

and

$$\phi_{nm} = \frac{\sum_i a_{ni} \eta_{im} E(y_i)}{\sum_i a_{ni} E(y_i)}, \tag{2.13}$$

where η_{ij} and ε_{ij} are uncompensated and compensated price elasticities of food *i* with respect to food price *j*, respectively; η_{im} is the expenditure elasticity for the *i*th food; a_{ni} is the quantity of nutrient n per unit of food *i*; and $E(y_i)$ is the expected physical consumption of the *i*th food. Thus, equations (2.12) and (2.13) express the fact that the nutrient-price and

nutrient-expenditure elasticities are the weighted average of all own-, cross-price, and expenditure elasticities, respectively. In other words, Pitt assumed that consumers have complete knowledge about the levels of nutrients in various food items.

Pitt estimated the nutrient-price and nutrient-expenditure elasticities for a food system consisting of nine food items and nine nutrients. Given the matrix of estimated nutrient-price elasticities in rural Bangladesh, Pitt concluded that wheat flour would be an ideal candidate if it were decided that subsidies would be used to achieve nutritional objectives. Pitt also discovered that wheat flour constitutes a significant portion of the food consumption of the poor but a small portion consumption of the rich. In fact, its demand elasticity with respect to total food expenditure is negative over the entire range of expenditure studied. In addition, Pitt concluded that poor consumers are much more responsive to wheat flour price than are wealthier consumers. Rogers and Levinson (1976) also document that wheat flour, particularly pre-ground wheat flour, has these same attributes in Pakistan and that its subsidization is effectively targeting nutritionally deficient households.

Lancaster (1966) developed a novel conceptual framework to link food choice and nutritional status. The chief novelty stems in breaking away from the classical approach that goods (foods) are the direct objects of utility and, instead, supposes that it is the properties or characteristics of the goods (foods) from which utility is derived. In this sense, consumers attain the nutrient characteristics that they most desire from the consumption activity by maximizing utility as a function of nutrient characteristics, as opposed to food quantities in classical demand theory. The consumer choice problem is then to maximize the utility function with respect to the budget constraint and a set of transformation equations that link nutrient availability to food consumption activities. However, this approach is rather difficult to

implement empirically, as Lancaster recognized, because a nonlinear programming problem needs to be solved to obtained the nutritional implication of food consumption. Although Lancaster's study is a purely conceptual framework, it is a breakthrough to the classical utility theory. In considering the literature review on demand analysis, his study has led the way to many subsequent studies (Brown and Schrader, 1990; Capps and Schmitz, 1991; Chang and Kinnucan, 1991; Huang, 1996) and is worthy of recognition.

A recent study by Huang (1996) explored the linkage of the determinants for food choice based on consumer nutrient availability using Lancaster's "consumption technology" of consumer behavior or the linear characteristic model, which is

$$\Phi_h = \sum_i a_{hi} q_i, \tag{2.14}$$

where a_{hi} is the amount of the *h*th nutrient contained in a unit of the *i*th food, q_i. Equation (2.14) states that the total amount of one particular nutrient (Φ_h) can be expressed as a sum of the *h*th nutrient contained in all foods. This technology allows the transformation of food demands into nutrient availability, which plays the central role in Huang's study. He then expressed the relative changes of consumer nutrient availability as a function of the relative changes in food prices and per capita income, which is

$$\begin{aligned} d\Phi_h/\Phi_h &= \sum_j \left(\sum_i \eta_{ij} a_{hi} q_i/\Phi_h\right) dp_j/p_j + \left(\sum_i \eta_{im} a_{hi} q_i/\Phi_h\right) dm/m \\ &= \sum_j \zeta_{ij} dp_j/p_j + \rho_h dm/m, \end{aligned} \tag{2.15}$$

where $\eta_{ij} = \partial(\log q_i)/(\partial \log p_j)$ is the demand elasticity of the *i*th food with respect to the *j*th food price; $\eta_{im} = \partial(\log q_i)/\partial(\log m)$ is the income elasticity for the *i*th food; m is per capita income or expenditure; $\zeta_{ij} = \sum_i \eta_{ij} a_{hi} q_i/\Phi_h$ is a price elasticity measuring the effect of the *j*th food price on the availability of the *h*th nutrient and is the weighted average of all own- and cross-price elasticities, η_{ij}s, in response to the *j*th price, with each weight expressed as the

share of each food's contribution to the *h*th nutrient $(a_{hi}q_i/\Phi_h)$s; $\rho_h = \sum_i \eta_{im} a_{hi} q_i / \Phi_h$ is an income elasticity, which measures the effect of income on the availability of nutrients, is simply the weighted average of all income elasticities, η_{im}s, with each weight again expressed as the share of each food's contribution to the *h*th nutrient. Again, this transformation of price and expenditure to nutrient-price and nutrient-expenditure elasticities is based on the assumption that consumers know the proportions of various nutrients embodied in various food items, the same assumption that is used in Pitt's study (1983).

A food system composed of 35 food categories and 15 nutrients was analyzed by Huang, and the respective nutrient-price and nutrient-expenditure elasticities were reported. The estimated nutrient elasticities have both positive and negative signs when food prices change, depending on how price changes manifest themselves through own- and cross-price elasticities. The calculated nutrient income elasticities ranged from 0.138 to 0.388.

As pointed out by Huang, there are limitations in using disappearance data to derive the elasticities for changes in the nutritional content of consumer diets. For example, the nutrition information used in Huang's study is the nutritive values of the edible portion of food items that do not directly relate to the disappearance quantities. Therefore, the nutrient elasticities estimated by Huang were under the assumption that the edible portions and disappearance quantities are identical which, if untrue, might result in biased estimates of nutrient elasticities.

The estimated nutrient-expenditure elasticities from Pitt's and Huang's studies are summarized in Table 2-4. In Pitt's (1983) study, results were presented for two representative households. The higher expenditure household, labeled "percentile 25," has a level of per capita food expenditure that is greater than 75 percent of the households sampled, and the

Table 2-4. Nutrient Expenditure Elasticities from Two Selected Studies.

	Pitt		Huang
Nutrient	Percentile 25 Expenditure	Percentile 90 Expenditure	
Protein	0.79	0.64	0.277
Fat	1.13	0.79	0.388
Carbohydrate	0.80	0.81	0.138
Calories/Energy	0.82	0.78	0.266
Calcium	1.08	0.65	0.329
Iron	0.60	0.45	0.217
Thiamin	0.65	0.50	0.257
Riboflavin	0.79	0.58	0.262
Niacin	0.76	0.71	0.229
Cholesterol			0.306
Phosphorus			0.305
Potassium			0.321
Sodium			0.349
Vitamin A			0.344
Vitamin C			0.337

lower expenditure household, labeled "percentile 90," has a level per capita food expenditure that is greater than 10 percent of the households sampled. In Pitt's study, the nutrient-expenditure elasticities ranged from 0.6 for iron to 1.13 for fat for the 25 percentile expenditure group and from 0.45 for iron to 0.81 for carbohydrate for the 90 percentile expenditure group. In Huang's (1996) study, these nutrient-expenditure elasticities ranged from 0.138 for carbohydrate to 0.388 for fat. Surprisingly, in Pitt's study, the magnitude of nutrient-expenditure elasticities for poor households is less than that of wealthier households. Both positive and negative nutrient-price elasticities were reported in these two studies. Comparing the nutrient-expenditure elasticities in these two studies, Pitt's estimates are relatively higher than Huang's. The possible interpretation might be that there are more food categories and nutrients analyzed in Huang's study, given the adding-up condition that requires the individual nutrient-expenditure elasticities be relatively smaller as in Huang's case. However, it might be a different case that the estimates from these two studies are not comparable given the fact that income levels, demographic variables, etc., are different between the United States and Bangladesh.

Approaches

Knowledge of a complete set of nutrient-price and expenditure elasticities is important when generating nutrition-oriented food policy and programs. However, as mentioned above, not many studies have been conducted in this particular area. Pitt (1983) and Huang (1996) used the linear characteristic model to directly convert the price and expenditure elasticities to the nutrient-price and nutrient-expenditure elasticities. However, this linear characteristic model stems from the assumption that consumers have full knowledge about the nutritional

contents in all food items considered. Moreover, the demand models that Pitt and Huang used have no theoretical basis.

On the other hand, the hedonic price model is a special case of the household production model (Deaton and Muellbauer, 1980). That is , the shadow (implicit) prices for nutrients can be estimated. Then the household's full food cost or expenditure can be expressed and solved as a function of its utility, input prices, and its capital stocks.

The above discussion shows that, under different assumptions, the demand for nutrients or the influence of nutrients on the demand for food can be modeled differently. The first group of researchers (for example, Capps and Schmitz; Chang and Kinnucan; Gould, Cox, and Perali) assumed that nutrients change consumers' tastes and preferences; therefore, nutrients enter directly into the utility function and are treated in demand specifications in the same manner as prices and income. The second group of researchers (for example, Morgan et al.; Cook and Eastwood; Eastwood, Brooker, and Terry; Huffman; Morgan) suggest that consumers demand nutrients rather than market foods; therefore, shadow prices of nutrients can be estimated as functions of the nutrient content of different food items. The third group of researchers (for example, Pitt; Huang) derived the impact of nutrients on food demand using the physical relationships among nutrient contents and the food consumed and regular demand relationships. The fourth group of researchers (for example, Akin et al.; Basiotis et al.; Chavas and Keplinger; Scearce and Jensen) assume that the demand for nutrients are functions of household demographics.

The models used by the first group researchers are ad hoc. For example, the Rotterdam demand system used in the Capps and Schmitz study is inconsistent with the proper specification derived by Barten (1964a); the AIDS model used by Gould, Cox, and Perali was

not derived directly from the cost function specified by Deaton and Muellbauer; and the demand relationship specified in the Chang and Kinnucan's study is not even a demand system.

The assumption behind the models used by the second and the third groups of researchers is that consumers demand nutrients directly, which involves the transformation from market goods (food items) to non-market goods (nutrients). The linear characteristics model and the hedonic price models used by these researchers are special cases of the household production model proposed by Stigler and Becker (1977). The household production model allows more flexible relationships between the demand for nutrients and market goods than both the linear characteristics model and the hedonic model.

In order to study the impact of nutrients on the demand for food and the demand for nutrients themselves, two formal demand models will be developed in this study. Under the assumption that both the quantities of foods and nutrients affect consumer's utility, the general (homogeneity, symmetry, Cournot aggregation, and Engel aggregation conditions) and specific demand restrictions pertaining to nutrients will be examined. A levels version of the Rotterdam model will be developed to incorporate these general and specific demand restrictions. In addition, a household production model will be developed to study the derived demand for nutrients using the estimated nutrient shadow prices.

CHAPTER 3
THE EXTENDED LEVELS VERSION OF THE ROTTERDAM MODEL

In order to incorporate nutrient variables in the food demand systems, two approaches are developed in this study. In the first approach, it is assumed that both food quantities and nutrients affect a representative consumer's utility function (Basmann, 1956; Phlips, 1974). As shown in chapter 2, two of the most popular demand systems are the Rotterdam model and the AIDS. Using scaling technique, it is possible to properly incorporate nutrient variables in the AIDS; however, the resulting model becomes quite complex and difficult to estimate. In addition, the regular Rotterdam model (defined in logarithmic differences) cannot be used with cross-sectional data; therefore, Barten's (1989) levels version of the Rotterdam model will be considered. In this approach, a levels version of the Rotterdam model, extended with nutrient variables, is derived. In this model, the price, income, and the own- and cross-nutrient demand elasticities can be calculated directly, and the theoretical constraints -- such as adding-up, homogeneity, and symmetry -- are preserved.

The second approach is based on the household production theory (Becker, 1965; Mincer, 1962; Lancaster, 1966; Michael and Becker, 1973; Stigler and Becker, 1977). A household production model is therefore specified and will be presented and discussed in the next chapter. This chapter, which has five sections, mainly focuses on the extended levels version of the Rotterdam model. In the first section, the derivation of the extended levels version of the Rotterdam model is shown. The estimation methods are then presented and discussed in the following section. In the third section, data problems in terms of estimation

are stated, and a summary of data is also provided. Since knowledge of the sources of nutrients is the key to a healthy diet, basic nutritional information is presented in the fourth section. In the final section, estimation results from this extended levels version of the Rotterdam model are reported and summarized.

The Derivation of the Extended Levels Version of the Rotterdam Model

General Demand Restrictions

The levels version of the Rotterdam model is based upon the traditional consumer demand theory, or utility theory. The traditional consumer demand theory assumes that a typical individual maximizes his utility by consuming products subject to his budget constraint: that is,

$$\max\ u = u(q) \text{ s.t. } \mathbf{p}'\mathbf{q} = m, \tag{3.1}$$

where u is the utility function, **p** and **q** are vectors of commodity prices and quantities, respectively, and m refers to total expenditure or income. In general, **q** consists of all commodity quantities consumed -- such as shelter, food, clothes, entertainment, and transportation, etc. The demand equations under the framework of (3.1) have a general form:

$$q_i = q_i(\mathbf{p}, m), \tag{3.2}$$

which indicates that the demand for an individual commodity is a function of prices for all n commodities and total expenditure or income. Several restrictions on demand parameters implied by theory can be derived. In particular, these restrictions are Engel aggregation or adding-up condition, Cournot aggregation, symmetry, and homogeneity. The adding-up restriction (Frisch, 1959) states that the weighted (by the budget shares) sum of the income elasticities is unity, which can be written as

$$\begin{aligned}&\mathbf{p}'\mathbf{q}_{\mathbf{m}} = 1, \quad \text{or}\\ &\sum_i p_i(\partial q_i/\partial m) = \sum_i \partial p_i q_i/\partial m = 1, \quad \text{or}\\ &\sum_i w_i \eta_{im} = 1,\end{aligned} \tag{3.3}$$

where $\mathbf{q_m}' = [\partial q_1/\partial m, \ldots, \partial q_n/\partial m]$, the vector of commodity quantity derivatives with respect to income; $\partial(p_i q_i)/\partial m$ is the marginal propensity to spend on commodity *i* (or its marginal budget share); $w_i = p_i q_i/m$ is the average budget share for the commodity *i*; and $\eta_{im} = \partial(\log q_i)/\partial(\log m)$ is the income elasticity with respect to q_i.

The Cournot aggregation restriction expresses the weighted column sum of the price elasticities as the negative of the budget share on the *j*th commodity:

$$\begin{aligned}&\mathbf{p}'\mathbf{Q}_{\mathbf{p}} = -\mathbf{q}', \quad \text{or}\\ &\sum_i p_i(\partial q_i/\partial p_j) = -q_j, \quad \text{or}\\ &\sum_i w_i \eta_{ij} = -w_j,\end{aligned} \tag{3.4}$$

where $\mathbf{Q_p}$ is a (n x n) matrix of the price derivatives of $q_i s$; and $\eta_{ij} = (\partial \log q_i/\partial \log p_j)$ is the price elasticity of commodity *i* with respect to commodity *j*.

The symmetry restriction simply states that the matrix of compensated cross-price substitution effect is symmetric, which follows by the symmetry of $\mathbf{H}^{-1}$; the inverse of the Hessian, **H**, of the utility function with respect to quantities. The Hessian is

$$\mathbf{H} = \begin{bmatrix} \partial u^2/\partial q_1^2 & \partial u^2/\partial q_1 \partial q_2 & \ldots & \partial u^2/q_1 \partial q_n \\ \partial u^2/\partial q_2 q_1 & \partial u^2/\partial q_2^2 & \ldots & \partial u^2/\partial q_2 q_n \\ \cdot & \cdot & \ldots & \cdot \\ \cdot & \cdot & \ldots & \cdot \\ \cdot & \cdot & \ldots & \\ \partial u^2/\partial q_n \partial q_1 & \partial u^2/\partial q_n \partial q_2 & \ldots & \partial u^2/\partial q_n^2 \end{bmatrix}. \tag{3.5}$$

The symmetry condition can be written as

$$
\begin{aligned}
&(\mathbf{Q_p} + \mathbf{q_m q}')' = \mathbf{Q_p} + \mathbf{q_m q}', \quad \text{or} \\
&(\partial q_i/\partial p_j) + (\partial q_i/\partial m)q_j = (\partial q_j/\partial p_i) + (\partial q_j/\partial m)q_i, \quad \text{or} \\
&s_{ij} = s_{ji}, \quad \text{or} \\
&\eta_{ij} = (w_j/w_i)\eta_{ji} - w_j(\eta_{im} - \eta_{jm}),
\end{aligned}
\tag{3.6}
$$

where $s_{ij} = (\partial q_i/\partial q_j) + (\partial q_i/\partial m)q_j$ is the price substitution effect of demand price slope with utility held constant.

The homogeneity condition implies that the consumer does not exhibit money illusion. In other words, consumers' commodity purchase decisions of commodities are made on the basis of relative prices and income: that is,

$$
\begin{aligned}
&\mathbf{Q_p p} = -\mathbf{q_m} m, \quad \text{or} \\
&\sum_j p_j(\partial q_i/\partial p_j) + m(\partial q_i/\partial m) = 0, \quad \text{or} \\
&\sum_j s_{ij} p_j = 0, \quad \text{or} \\
&\sum_j \eta_{ij} = -\eta_{im}.
\end{aligned}
\tag{3.7}
$$

Note that demand functions, which satisfy the symmetry and the Cournot aggregation constraints, are automatically homogenous.

Demand System with Additional Variables

Assuming that variables in addition to quantities affecting consumer's utilities, the consumer choice problem can be written as (Barten, 1964b; Phlips, 1974)

$$\max\ u = u(\mathbf{q}, \mathbf{x}) \text{ s.t. } \mathbf{p}'\mathbf{q} = m, \tag{3.8}$$

where $\mathbf{x}$ is a vector consisting of v variables other than $\mathbf{p}$, $\mathbf{q}$, and m. The demand equations satisfying (3.8) have the general form

$$q_i = q_i(\mathbf{p}, \mathbf{x}, m), \tag{3.9}$$

indicating that demand for a particular commodity by a utility-maximizing consumer depends on the prices for all n commodities, the total expenditure, and a set of additional variables affecting the utility function.

The effects of an additional variable, x_h, can also be related to the substitution effects of price changes (Barten, 1964b; Phlips, 1974), which is

$$
\begin{aligned}
&Q_x = -\frac{1}{\lambda}\sum_j s_{ij}\Xi_{jh}, \quad \text{or} \\
&\partial q_i/\partial x_h = -\frac{1}{\lambda}\sum_j (\partial q_i/\partial p_j + (\partial q_i/\partial m) q_j)[\partial^2 u/\partial q_j \partial x_h], \\
&\qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v,
\end{aligned} \tag{3.10}
$$

where Q_x is a (n x v) matrix of quantity derivatives with respect to variables $\mathbf{x}$, that is, $(\partial q_i/\partial x_h)$, $i = 1, \ldots, n$, $h = 1, \ldots, v$; $\Xi_{jh} = \partial^2 u/(\partial q_j \partial x_h)$ is the effect of variables x_h on the marginal utility of commodity *j*.

Multiplying both sides of (3.10) by $(p_i q_i/m)(x_h/q_i)$, one has

$$
\begin{aligned}
&(p_i q_i/m)\ (\partial q_i/\partial x_h)\ (x_h/q_i) = -\sum_j (p_i p_j/m) s_{ij}[\partial^2 u/(\partial q_j \partial x_h)]\ (x_h/\lambda p_j) \\
&(p_i q_i/m)\ (\partial \log q_i/\partial \log x_h) = w_i(\partial \log q_i/\partial \log x_h) = \sum_j -\pi_{ij}\xi_{jh}, \\
&\qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v,
\end{aligned} \tag{3.11}
$$

where $\pi_{ij} = (p_i p_j/m) s_{ij}$ and $\xi_{jh} = \Xi_{jh}(x_h/\lambda p_j) = [\partial^2 u/(\partial q_j \partial x_h)](x_h/\lambda p_j) = \partial \log(\partial u/\partial q_j)/\partial \log x_h = [\partial(\partial u/\partial q_j)/\partial x_h)](x_h/\lambda p_j)$ is the elasticity of the marginal utility of commodity *j* with respect x_h and is assumed to be constant for all commodities, using the first-order condition of utility maximization, $\lambda p_j = \partial u/\partial q_j$.

A basic property of demand systems with factors such as variables $\mathbf{x}$ is that any demand increase(s) as a result of a change in the factor must be offset by a demand decrease(s) for other commodities as total expenditure remains unchanged (for example, the

Engel aggregation or adding-up condition). In other words, this property can be derived by summing over *i* of (3.10)

$$\sum_i p_i \partial q_i / \partial x_h = 0, \quad \text{or}$$
$$\sum_i w_i (\partial \log q_i / \partial \log x_h) = 0, \quad i, = 1,\dots,n; \; h = 1,\dots,v, \tag{3.12}$$

where $\partial \log q_i / \partial \log x_h$ is the elasticity of demand for commodity *i* with respect to variable x_h. Equation (3.12) states that the weighted sum of demand elasticities for commodity *i* with respect to an additional variable is zero where the weights are the commodity budget shares.

Under the framework of (3.8), all the theoretically derived restrictions (3.3), (3.4), (3.6), and (3.7) are indeed valid (Phlips, 1974). Moreover, an additional restriction, shown in (3.12), associated with the adding-up condition can be derived.

The Levels Version of the Rotterdam Model with Additional Variables

Barten (1989) and Bewley (1986) have recently developed demand models that might be characterized as levels versions of the Rotterdam model. The Rotterdam model (Barten, 1964a; Theil, 1965) is generally specified in logarithmic first differences and is thus employed for analyzing time-series data. On the other hand, the levels versions provide demand researchers an alternative specification for analyzing cross-sectional data or modeling dynamics that may be difficult to apprehend using first differences (Barten, 1989).

Since cross-sectional data from the 1987-88 National Food Consumption Survey (NFCS) are used for this study, the levels version of the Rotterdam model is therefore used. Based on equation (3.9), a double-logarithmic demand equation with an intercept term and the additional variables **x** can be written as

$$\log q_i = \alpha_{i0}' + \eta_{im}\log m + \sum_j \eta_{ij}\log p_j + \sum_h \varepsilon_{ih}\log x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v, \tag{3.13}$$

where α_{i0}' is the intercept term; $\eta_{im} = (\partial \log q_i / \partial \log m)$ is the income elasticity; $\eta_{ij} = (\partial \log q_i / \partial \log p_j)$ is the uncompensated price elasticity; and $\varepsilon_{ih} = (\partial \log q_i / \partial \log x_h)$ is the demand elasticity of commodity *i* with respect to x_h.

An alternative version of (3.13) can be obtained by using the Slutsky (or compensated) elasticities, which have the form

$$\log q_i = \alpha_{i0}' + \eta_{im}(\log m - \sum_j w_j \log p_j) + \sum_j \varepsilon_{ij}\log p_j + \sum_h \varepsilon_{ih}\,\mathrm{og}\, x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v, \tag{3.14}$$

where $\varepsilon_{ij} = \eta_{ij} + \eta_{im}w_j$ is the compensated or Slutsky price elasticities of commodity *i* with respect to commodity *j*.

Using the relationship

$$\log m = \sum_j w_j \log q_j + \sum_j w_j \log p_j - \sum_j w_j \log w_j, \quad j = 1,\ldots,n, \tag{3.15}$$

and letting $\log Q = \sum_j w_j \log q_j$ be the Stone volume index and $\log P = \sum_j w_j \log p_j$ be the Stone price index, equation (3.14) can be rewritten as

$$\log q_i = \alpha_{i0}' + \eta_{im}\log Q + \sum_j \varepsilon_{ij}\log p_j + \sum_h \varepsilon_{ih}\log x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v. \tag{3.16}$$

Note that the term $\sum_j w_j \log w_j$ in equation (3.15) tends to vary little and is omitted from (3.15) in specifying the levels version of the Rotterdam model (3.16).

Multiplying both sides of (3.16) by w_i and using $\mu_i = w_i\eta_{im}$ $(= p_i(\partial q_i/\partial m)$, the marginal propensity to spend on commodity *i*), $\pi_{ij} = w_i\varepsilon_{ij}$ (that is, the Slutsky term in the

Rotterdam model), and $\gamma_{ih} = w_i\varepsilon_{ih}$, one obtains (Aviphant, Lee, and Brown, 1988; Barten, 1989; Brown, 1994; Selvanathan, 1989; Theil, 1980):

$$w_i \log q_i = \alpha_{i0} + \mu_i \log Q + \sum_j \pi_{ij} \log p_j + \sum_h \gamma_{ih} \log x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v, \tag{3.17}$$

where $\alpha_{i0} = w_i\alpha_{i0}'$. Therefore, (3.17) is the levels version of the Rotterdam model with additional variables $\mathbf{x}$. The adding-up conditions require that $\sum_i \alpha_{i0} = 0$, $\sum_i \mu_i = 1$, $\sum_i \pi_{ij} = 0$, and $\sum_i \gamma_{ih} = 0$; the homogeneity condition requires that $\sum_j \pi_{ij} = 0$; and the symmetry condition requires that $\pi_{ij} = \pi_{ji}$. Using relation in (3.11), model (3.17) can be written as

$$w_i \log q_i = \alpha_{i0} + \mu_i \log Q + \sum_j \pi_{ij} (\log p_j - \sum_h \xi_{jh} \log x_h), \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v. \tag{3.18}$$

Both models (3.17) and (3.18) are specified in absolute price version. Equation (3.17) can also be written in the relative price version using the relationships $\pi_{ij} = \phi\mu_{ij} - \phi\mu_i\mu_j = v_{ij} - \phi\mu_i\mu_j$, where $\phi = (\partial \log\lambda / \partial \log m)^{-1}$ is the reciprocal of the income elasticity of marginal utility of income, or flexibility of income; $\mu_{ij} = (\frac{\partial\lambda}{\partial m}) p_i p_j u^{ij}$; $\sum_j \mu_{ij} = \mu_i$; $v_{ij} = \phi\mu_{ij} = (\frac{\lambda}{m}) p_i u^{ij} p_j$; and u^{ij} is the (i, j)th element of $\mathbf{H}^{-1}$. Accordingly, (3.17) can be rewritten as

$$w_i \log q_i = \alpha_{i0} + \mu_i \log Q + \phi \sum_j \mu_{ij} \log(\frac{p_j}{P'}) + \sum_h \gamma_{ih} \log x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v. \tag{3.19}$$

or

$$w_i \log q_i = \alpha_{i0} + \mu_i \log Q + \sum_j v_{ij} \log(\frac{p_j}{P'}) + \sum_h \gamma_{ih} \log x_h, \qquad i,j = 1,\ldots,n;\ h = 1,\ldots,v, \tag{3.20}$$

where $\log P' = \sum_j \mu_j \log p_j$ is the Frisch price index of a complete basket of n commodities in the system. The demand restrictions are $\sum_i \mu_i = 1$, $\sum_i \pi_{ij} = 0$, and $\sum_i \gamma_{ih} = 0$ for the

adding-up condition; $\sum_j \pi_{ij} = 0$ for the homogeneity condition; and $\mu_{ij} = \mu_{ji}$ (or $\nu_{ij} = \nu_{ji}$), or $\pi_{ij} = \pi_{ji}$ for the symmetry condition.

Block Independence and the Conditional Demand Equations

In general, a study focuses on a particular commodity or group of commodities. Moreover, data beyond this particular commodity group are generally not available. Thus, one might consider a subsystem analysis that can be derived theoretically from a full-system demand model under certain assumptions. In many cases, the number of consumer goods is large, and the estimation of their demand equations requires constraints on the utility function in order to deal with the problem of degrees of freedom. The most frequently used constraints are the separability assumptions on the utility function. The separation amounts to combining goods into groups of goods in such a way that group utility functions play a role. This approach was introduced by Leontief (1947) and Sono (1961) and was further elaborated by Strotz (1957 and 1959), Goldman and Uwaza (1964), Barten and Turnovsky (1966), and Gorman (1959 and 1968). Geary and Morishima (1973) provided a good survey of the literature until 1970.

As data for commodities other than food are not available in the 1987-88 NFCS, the assumption of block independence is used in this study to derive a sub-demand system for food. Block independence assumes that the marginal utility of a commodity in a group is independent of the quantities of commodities that do not belong to the same group. Formally, assume that there are F (< n) groups of commodities, $G_1, \ldots, G_F$, such that each commodity belongs to exactly one group and that the additional variables **x**, the nutrient variables, only affect the utility of the food group, u_F. Then, the utility function under the

assumption of block independence can be written as

$$u = u_1(q_1) + u_2(q_2) + \ldots + u_{F-1}(q_{F-1}) + u_F(q_F, x), \tag{3.21}$$

where $q_1, \ldots, q_F$ represents the commodity quantity for groups 1, . . . , F, respectively; $u_1, \ldots, u_F$ are the associated utilities or subutilities derived from consuming these commodities; and **x** is a (n_F x H) matrix of nutrient variables: that is,

$$x = [x_{jh}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1H} \\ x_{21} & x_{22} & \cdots & x_{2H} \\ \vdots & \vdots & & \vdots \\ x_{n_F1} & x_{n_F2} & \cdots & x_{n_FH} \end{bmatrix}, \quad j = 1, \ldots n_F;\ h = 1, \ldots, H. \tag{3.22}$$

x_{jh} is the nutrient *h* embodied in food *j*, n_F and H are the number of food commodities and nutrients, respectively, in the food group G_F. Equation (3.21) simply expresses that, under the assumption of block independence, the utility a representative consumer can obtain is the sum of all subutilities derived from the different commodity groups that he consumes.

The advantage of block structures is that the expenditure allocation for the group in question is irrelevant from other groups, or that a consumer's utility in (3.21) is maximized as subutilities u_f, $f = 1, \ldots, F$, are maximized. In this sense, two-stage budgeting can then be applied, and a conditional demand for an individual food item within the food group can be derived (Theil, 1976; Deaton and Muellbauer, 1980). For the two-stage budgeting, information confined to that stage only is required at each stage. At the first stage, given knowledge of total expenditure and appropriately defined group prices, allocation among groups is possible; while at the second stage, individual demands are functions of food group expenditure and prices within the food group only. Both of these allocations ought to be

perfect in the sense that the results of two-stage budgeting must be identical to what would happen if the allocation were made in one step with complete information. In short, the two-stage budgeting results from the assumptions of separability such as (3.21), which impose restrictions on the consumer's behavior (that is, the utility function), is the key ingredient to success of the subsystem analysis.

Under the assumption of block independence (3.21), the substitution effect, or the third term on the right-hand side (RHS) of (3.17), can be classified by its two different sources: one is the substitution effect within the food group, $\sum_{j\in G_F} \pi_{ij} \log p_j$, and the other is substitution effects from other groups, $\sum_{j\notin G_F} \pi_{ij} \log p_j$. Recall that $\pi_{ij} = \phi\mu_{ij} - \phi\mu_i\mu_j$. Block independence implies $\mu_{ij} = 0 \ \forall i \in G_F, \ j \notin G_F$. First, rearranging the substitution effect within the food group, one obtains

$$\begin{aligned} \sum_{j\in G_F} \pi_{ij} \log p_j &= \sum_{j\in G_F} (\phi\mu_{ij} - \phi\mu_i\mu_j) \log p_j \\ &= \phi \sum_{j\in G_F} \mu_{ij} \log p_j - \phi\mu_i \sum_{j\in G_F} \mu_j \log p_j, \end{aligned} \tag{3.23}$$

where p_j is the price for the *j*th food item in the food group. Then, rearranging the substitution effects from groups other than food using the relationship $\pi_{ij} = -\phi\mu_i\mu_j$, note that μ_{ij} vanishes when goods *i* and *j* belong to different commodity groups under the assumption of block independence. (Recall that $\phi\mu_{ij} = (\frac{\lambda}{m}) p_i u^{ij} p_j$; u^{ij} is the (*i*, *j*)th element of H^{-1}; and u^{ij} vanishes as i and j belong to different commodity groups. Thus, $\phi\mu_{ij}$ equals zero, and μ_{ij} equals zero given that ϕ does not equal zero.) One obtains that

$$\begin{aligned} \sum_{j\notin G_F} \pi_{ij} \log p_j &= \sum_{j\notin G_F} (-\phi\mu_i\mu_j) \log p_j \\ &= -\phi\mu_i \sum_{j\notin G_F} \mu_j \log p_j. \end{aligned} \tag{3.24}$$

Combining these two substitution terms in (3.23) and (3.24), one obtains

$$\begin{aligned}
&\sum_{j\in G_F} \pi_{ij}\log p_j + \sum_{j\notin G_F} \pi_{ij}\log p_j \\
&= \phi\sum_{j\in G_F} \mu_{ij}\log p_j - \phi\mu_i\sum_{j\in G_F} \mu_j\log p_j - \phi\mu_i\sum_{j\notin G_F} \mu_j\log p_j \\
&= \phi\sum_{j\in G_F} \mu_{ij}\log p_j - \phi\mu_i\sum_{j=1}^{n} \mu_j\log p_j.
\end{aligned} \tag{3.25}$$

Plugging (3.25) into equation (3.17), using the restriction $\mu_i = \sum_{j\in G_F} \mu_{ij}$, replacing j = 1 by k = 1, and rearranging terms, one can obtain

$$\begin{aligned}
w_i\log q_i &= \alpha_{i0} + \mu_i\log Q + \phi\sum_{j\in G_F} \mu_{ij}(\log p_j - \sum_{k=1}^{n} \mu_k\log p_k) \\
&\quad + \sum_{j\in G_F}\sum_{h\in G_F} \gamma_{ijh}\log x_{jh}, \\
&\sum_{j\in G_F} \mu_{ij} = \mu_i;\ i,j = 1,\ldots,n_F;\ h = 1,\ldots,H,
\end{aligned} \tag{3.26}$$

where the nutrient variables x_{jh} are defined in two dimensions that differ from the case in models (3.17)-(3.20) in which **x** is defined in one dimension.

Note that in the model (3.26) the Stone volume index (logQ) and Frisch price index ($\log P'$) are not confined to the food group, the estimation of (3.26) requires knowledge of commodities outside the food group. Therefore, a conditional demand subsystem (Theil, 1976), which consists of only the variables pertaining to the food group, needs to be derived.

Several notations in terms of food group need to be defined before the conditional demand function can be derived. They are

$$\begin{aligned}
\log Q_F &= \sum_{i\in G_F} \frac{w_i}{W_F}\log q_i, \quad \text{where } W_F = \sum_{i\in G_F} w_i, \quad \text{and} \\
\log P_F' &= \sum_{i\in G_F} \frac{\mu_i}{M_F}\log p_i, \quad \text{where } M_F = \sum_{i\in G_F} \mu_i.
\end{aligned} \tag{3.27}$$

By summing (3.26) over $i \in G_F$, one obtains a composite demand for the food group,

$$\sum_{i\in G_F} w_i \log q_i = \sum_{i\in G_F} \alpha_{i0} + \sum_{i\in G_F} \mu_i \log Q + \phi \sum_{i\in G_F}\sum_{j\in G_F} \mu_{ij}(\log p_j - \sum_{k=1}^{n} \mu_k \log p_k)$$
$$+ \sum_{i\in G_F}\sum_{j\in G_F}\sum_{h\in G_F} \gamma_{ijh} \log x_{jh}, \tag{3.28}$$
$$i,j = 1,\ldots,n_F;\ h = 1,\ldots,H,$$

or

$$W_F \log Q_F = \alpha_{F0} + M_F \log Q + \phi M_F(\log P_F' - \sum_{k=1}^{n} \mu_k \log p_k)$$
$$+ \sum_{j\in G_F}\sum_{h\in G_F} \gamma_{ijh}^{1} \log x_{jh}, \tag{3.29}$$
$$i,\ldots,n_F;\ h = 1,\ldots,H,$$

where $\alpha_{F0} = \sum_{i\in G_F} \alpha_{i0}$ and $\gamma_{ijh}^{1} = \sum_{i\in G_F} \gamma_{ijh}$.

Multiplying (3.29) by μ_i/M_F for $i \in G_F$, given that μ_i/M_F exists (because $M_F > 0$ holds under block independence), one obtains

$$(\mu_i/M_F)W_F \log Q_F = (\mu_i/M_F)\alpha_{F0} + \mu_i \log Q + \phi\mu_i(\log P_F'$$
$$- \sum_{k=1}^{n} \mu_k \log p_k) + (\mu_i/M_F)\sum_{j\in G_F}\sum_{h\in G_F} \gamma_{ijh}^{1} \log x_{ijh}, \tag{3.30}$$
$$i,j = 1,\ldots,n_F;\ h = 1,\ldots,H.$$

After arrangement of terms, subtracting (3.30) from (3.26) and using $\phi \sum_{i\in G_F} \mu_{ij} = \phi\mu_i$ (because of block independence), one can obtain the conditional demand for an individual food item within the food group, which is

$$w_i \log q_i = \alpha_{i0}^{F} + (\mu_i/M_F)W_F \log Q_F + \phi \sum_{j\in G_F} \mu_{ij}(\log p_j - \log P_F')$$
$$+ \sum_{j\in G_F}\sum_{h\in G_F} (\gamma_{ijh} - (\mu_i/M_F)\gamma_{ijh}^{1}) \log x_{jh}, \tag{3.31}$$
$$i,j = 1,\ldots,n_F;\ h = 1,\ldots,H;$$

$$w_i \log q_i = \alpha_{i0}^{F} + (\mu_i/M_F)W_F \log Q_F + \sum_{j\in G_F} \pi_{ij}^{F} \log p_j$$
$$+ \sum_{j\in G_F}\sum_{h\in G_F} \gamma_{ijh}^{F} \log x_{jh}, \tag{3.32}$$
$$i,j = 1,\ldots,n_F;\ h = 1,\ldots,H,$$

where $\gamma_{ijh}^{F} = \gamma_{ijh} - (\mu_i/M_F)\gamma_{ijh}^{1}$;

$$w_i \log q_i = \alpha_{i0}^{F} + (\mu_i/M_F)W_F \log Q_F + \sum_{j \in G_F} \pi_{ij}^{F}(\log p_j - \sum_{g \in G_F}\sum_{h \in G_F} \xi_{jgh} \log x_{gh}), \tag{3.33}$$
$$i,j,g = 1,\ldots,n_F;\ h = 1,\ldots,H,$$

where $\alpha_{i0}^{F} = (\alpha_{i0} - (\mu_i/M_F)\alpha_{F0})$; or

$\phi\sum_{j\in G_F} \mu_{ij}(\log p_j - \log P_F') = \phi\sum_{j\in G_F} \mu_{ij}\log p_j - \phi\mu_i\sum_{j\in G_F} (\mu_j/M_F)\log p_j = \sum_{j\in G_F} \pi_{ij}^{F}\log p_j$, using $\sum_{j\in G_F} \mu_{ij} = \mu_i$. This means that

$\pi_{ij}^{F} = \phi\mu_{ij} - \phi\mu_i\mu_j/M_F = \phi\mu_{ij} - \phi M_F(\mu_i/M_F)(\mu_j/M_F)$ is the conditional Slutsky coefficient; $\gamma_{ijh}^{F} = \pi_{ij}^{F}\xi_{jgh}$; and

$$\begin{aligned}\sum_{i\in G_F} \gamma_{ijh}^{F} &= \sum_{i\in G_F} (\gamma_{ijh} - (\mu_i/M_F)\gamma_{ijh}^{1}) \\ &= \sum_{i\in G_F} (\gamma_{ijh} - (\mu_i/M_F)\sum_{i\in G_F} \gamma_{ijh}) \\ &= \sum_{i\in G_F} \gamma_{ijh} - \sum_{i\in G_F} (\mu_i/M_F)\sum_{i\in G_F} \gamma_{ijh} \\ &= \sum_{i\in G_F} \gamma_{ijh} - (M_F/M_F)\sum_{i\in G_F} \gamma_{ijh} \\ &= 0,\end{aligned} \tag{3.34}$$

expressing that the sum of weighted demand elasticities of food item *i* with respect to the *h*th nutrient contained in the *j*th food item is equal to zero. In other words, the increase (decrease) in demand for a food item caused by any factor will be compensated by a decrease (increase) in demand for other food items in the food group as a whole. This is the adding-up condition that (3.12) implies.

A comparison of (3.32) and/or (3.33) with (3.26) shows that the same variable is shown on the left side but that the two indexes pertaining to the consumer's budget as a whole, $\log Q = \sum_i w_i \log q_i$ and $\log P' = \sum_k \mu_k \log p_k$, do not appear on the right-hand side of (3.32) and/or (3.33). In fact, the variables of (3.32) and/or (3.33) are exclusively pertaining to the group G_F where the *i*th food item belongs. Therefore, (3.32) and/or (3.33)

is the conditional demand equation of the ith commodity given the demand for G_F, that is, under the assumption of block-independence. In (3.32) and/or (3.33), the real income term is replaced by $W_F \log Q_F$, which can be interpreted as the volume component of the budget share of food group, W_F, and the contribution of the food group to the logarithm of real income, $\log Q_F$. The price logarithm, $\log p_j$, is deflated by the Frisch price index of the food group, $\log P_F'$, not by the Frisch price index of the complete basket, $\log P'$ as occurs in (3.26). The price coefficients are the same in (3.26) and (3.32) and/or (3.33), but the marginal share μ_i of (3.26) is replaced by the conditional marginal share μ_i/M_F in (3.32) and/or (3.33). The latter share answers the question: If income increases by one dollar so that the amount spent on the food group increases by M_F dollars, what proportion of these M_F dollars is allocated to the ith food item? Under the model (3.32) and/or (3.33), the adding-up condition implies that $\sum_{i \in G_F} \alpha_{i0}^F = 0$; $\sum_{i \in G_F} \mu_i/M_F = 1$; $\sum_{i \in G_F} \pi_{ij}^F = 0$; and $\sum_{i \in G_F} \gamma_{ijh}^F = 0$. The homogeneity implies $\sum_{j \in G_F} \pi_{ij}^F = 0$. Let $\Pi = [\pi_{ij}^F]$, which is symmetric and negative semidefinite of rank $(n_F - 1)$, where n_F is the total number of food items in the food group.

However, given the fact that data other than food commodities are not available from the 1987-88 NFCS, $w_i = p_i q_i / m$ is consequently not attainable because total expenditure m is not recorded. A modification to this model is required so that every variable belongs to the food group. This modification can be made by dividing both sides of equation (3.32) and (3.33) with W_F. Let $w_i^* = w_i/W_F$, $\mu_i^* = \mu_i/M_F$, $\phi_i^* = \phi_i/W_F$, $\gamma_{ijh}^* = \gamma_{ijh}^F/W_F$, and $\pi_{ij}^* = \pi_{ij}^F/W_F$. Then, (3.32) and (3.33) can be written as

$$\begin{aligned} w_i^* \log q_i &= \alpha_{i0}^* + \mu_i^* \log Q_F + \phi^* \sum_{j \in G_F} \mu_{ij}(\log p_j - \log P_F') \\ &\quad + \sum_{j \in G_F} \sum_{h \in G_F} \gamma_{ijh}^* \log x_{jh}, \qquad (3.35) \\ &\quad i,j = 1,\dots,n_F;\ h = 1,\dots,H, \end{aligned}$$

or

$$w_i^* \log q_i = \alpha_{i0}^* + \mu_i^* \log Q_F + \sum_{j \in G_F} \pi_{ij}^* \log p_j + \sum_{j \in G_F} \sum_{h \in G_F} \gamma_{ijh}^* \log x_{jh}, \quad i,j = 1,\ldots,n_F;\ h = 1,\ldots,H, \tag{3.36}$$

and

$$w_i^* \log q_i = \alpha_{i0}^* + \mu_i^* \log Q_F + \sum_{j \in G_F} \pi_{ij}^* (\log p_j - \sum_{g \in G_F} \sum_{h \in G_F} \xi_{jgh} \log x_{gh}), \quad i,j,g = 1,\ldots,n_F;\ h = 1,\ldots,H, \tag{3.37}$$

where $\alpha_{i0}^* = \alpha_{i0}^F / W_F$. Note that every variable in equations (3.35)-(3.37) pertains to the food group. They are the conditional demand equations for individual food items within the food group.

Recall that equation (3.10) states that the effects of additional variables can be related to the substitution effects of price changes. In context of this study, it can be written as

$$\begin{aligned} Q_x &= -\frac{1}{\lambda} \sum_{j \in G_F} s_{ij} \Xi_{jgh}, \quad \text{or} \\ \partial q_i / \partial x_{gh} &= -\frac{1}{\lambda} \sum_{j \in G_F} (\partial q_i / \partial p_j + (\partial q_i / \partial m) q_j)(\partial^2 u / \partial q_j \partial x_{gh}), \\ & i,j,g = 1,\ldots,n_F;\ h = 1,\ldots,H. \end{aligned} \tag{3.38}$$

Restrictions can be imposed on the structure of $[\Xi_{jgh}]$, a matrix of $(n_F \times n_F H)$. Equation (3.38) can be used to reduce the number of parameters to be estimated in the demand subsystem. Theil (1980) and Duffy (1987, 1989, 1990) assumed $\Xi_{jgh} = 0$ for $j \neq g$, that is, nutrients from food group g do not have impact on the marginal utility of food group j. In this case, (3.38) can be written as

$$\begin{aligned} Q_x &= -\frac{1}{\lambda} s_{ij} \Xi_{jjh}, \quad \text{or} \\ \partial q_i / \partial x_{jh} &= -\frac{1}{\lambda} (\partial q_i / \partial p_j + (\partial q_i / \partial m) q_j)(\partial^2 u / \partial q_j \partial x_{jh}), \\ & i,j = 1,\ldots,n_F;\ h \in j, \end{aligned} \tag{3.39}$$

or

$$w_i(\partial \log q_i/\partial \log x_{jh}) = \gamma_{ijh} = -\pi^F_{ij}\xi_{jjh}, \quad i,j = 1,\ldots,n_F;\ h\in j, \tag{3.40}$$

using the first-order condition, $\partial u/\partial q_j = \lambda p_j$, for utility maximization, where $\pi^F_{ij} = (p_i p_j / m)s_{ij}$, the conditional Slutsky coefficient of the Rotterdam model; and $\xi_{jjh} = \partial[\log(\partial u/\partial q_j)]/\partial \log x_{jh}$, the elasticity of the marginal utility of good *j* with respect to its own nutrient contents if $g = j$.

Dividing equation (3.40) by W_F and imposing this restriction on models (3.36) and (3.37), one obtains

$$w_i^* \log q_i = \alpha^*_{i0} + \mu^*_i \log Q_F + \sum_{j\in G_F} \pi^*_{ij} \log p_j + \sum_{j\in G_F} \sum_h \gamma^*_{ijh} \log x_{jh}, \quad i,j = 1,\ldots,n_F,\ h\in j, \tag{3.41}$$

and

$$w_i^* \log q_i = \alpha^*_{i0} + \mu^*_i \log Q_F + \sum_{j\in G_F} \pi^*_{ij} (\log p_j - \sum_h \xi_{jjh} \log x_{jh}), \quad i,j = 1,\ldots,n_F;\ h\in j. \tag{3.42}$$

Note that (3.41) and (3.42) are the conditional demand equations for individual food items in the food group under the assumptions that the marginal utility of a food item is independent of the quantities of commodities that do not belong to the food group and that the matrix of the impacts of nutrient variables on the marginal utility of food quantities are diagonal, that is, $\Xi_{jgh} = 0$ for $j \neq g$. The number of nutrient coefficients, γ_{ijh}s, that need to be estimated in (3.41) is greatly reduced as compared to (3.36).

In this study, the α^*_{i0}s, μ^*_is, π^*_{ij}s, and γ^*_{ijh}s (and thus ξ_{jjh}s) are assumed to be constants. The interpretation of γ^*_{ijh} is straightforward. If γ^*_{ijh} is greater than zero, then there is a complementary relationship between the demand for food item *i* and nutrient *h* from food item *j*; on the other hand, if γ^*_{ijh} is negative, then there is a competitive relationship between the demand for food item *i* and nutrient *h* from food item *j*; and if γ^*_{ijh} is zero, then there is

no impact of nutrient *h* from food item *j* on the demand for food item *i*. Moreover, the nutrient elasticity of food demand can also be calculated from (3.41), a levels version of the Rotterdam model under the structure of block independence. For example, γ^{*}_{ijh}/w_i is the conditional nutrient elasticity of nutrient *h* from food item *j* for the demand for food item *i*.

The last term on the RHS of equation (3.42) can be written as

$$\begin{aligned} \log p_j^{*} &= (\log p_j - \sum_{h\in j} \xi_{jjh} \log x_{jh}) \\ &= \log(p_j / \prod_{h\in j} x_{jh}^{\xi_{jjh}}), \end{aligned} \tag{3.43}$$

which can be viewed as the perceived price of food item *j* adjusted by *h* nutrients embodied in the *j*th food. Technically, the impact of a change in x_{jh} on p_j^{*} can be expressed as $\partial \log p_j^{*} / \partial \log x_{jh} = -\xi_{jjh}$. If ξ_{jjh} is positive or $x_{jh}^{\xi_{jjh}}$ is greater than one, then an increase in nutrient *h* in food item *j* decreases the price perceived by the consumer for food item *j*. In other words, for a given market price, a valuable nutrient results in a lower "perceived" price and thus increases the demand of the respective food item. On the other hand, when ξ_{jjh} is negative or $x_{jh}^{\xi_{jjh}}$ is less than one, an increase in the nutrient *h* embodied in food item *j* increases the "perceived" price and decreases the demand for the food item *j*. In other words, if a consumer or a household considers the nutritional attributes valuable, his/her perceived price of the food item in question is lower than the actual price, which increases the consumption of the food item, and vice versa.

Estimation

In this study, a system approach is used to estimate both models (3.41) and (3.42). Note that the disturbances in (3.41) and (3.42) are mutually correlated. Suppose there are

n equations with T observations in the system in question, then this system of equations can be represented as

$$\begin{bmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ 0 & 0 & \cdots & X_n \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \cdot \\ \cdot \\ \cdot \\ \beta_n \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \cdot \\ \cdot \\ \cdot \\ \epsilon_n \end{bmatrix}, \tag{3.44}$$

where y_i is a (T x 1) vector; X_i is a (T x k_i) matrix; β_i is a (k_i x 1) vector; and ϵ_i is a (T x 1) vector, $i = 1, \ldots, n$.

An alternative representation of equation (3.44) is

$$y = X\beta + \epsilon, \tag{3.45}$$

where y is a (nT x 1) vector; X is a (nT x K) matrix; β is a (K x 1) matrix; and the dimension of ϵ is (nT x 1). Note that $K = \sum_i k_i$. In this case of correlated disturbances, the variance-covariance matrix is assumed as

$$E(\epsilon_i \epsilon_j') = \sigma_{ij} I_T \quad i,j = 1,\ldots,n, \tag{3.46}$$

or

$$\Omega = E(\epsilon\epsilon') = \begin{bmatrix} E(\epsilon_1\epsilon_1') & E(\epsilon_1\epsilon_2') & \cdots & E(\epsilon_1\epsilon_n') \\ E(\epsilon_2\epsilon_1') & E(\epsilon_2\epsilon_2') & \cdots & E(\epsilon_2\epsilon_n') \\ \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdots & \\ \cdot & \cdot & \cdots & \\ E(\epsilon_n\epsilon_1') & E(\epsilon_n\epsilon_2') & \cdots & E(\epsilon_n\epsilon_n') \end{bmatrix}, \tag{3.47}$$

or

$$\Omega = \begin{bmatrix} \sigma_{11}\mathbf{I}_T & \sigma_{12}\mathbf{I}_T & \cdots & \sigma_{1n}\mathbf{I}_T \\ \sigma_{21}\mathbf{I}_T & \sigma_{22}\mathbf{I}_T & \cdots & \sigma_{2n}\mathbf{I}_T \\ \vdots & \vdots & & \vdots \\ \sigma_{n1}\mathbf{I}_T & \sigma_{n2}\mathbf{I}_T & \cdots & \sigma_{nn}\mathbf{I}_T \end{bmatrix} = \Sigma \otimes \mathbf{I}_T, \tag{3.48}$$

where $\mathbf{I}_T$ represents a (T x T) identity matrix. σ_{ij} is the covariance of the disturbance of the *i*th and the *j*th equation, which is assumed to be constant over all observations. This system of n equations is thus called a system of seemingly unrelated regression equations because of these subtle links between equations. Note that generalized least squares (GLS) and maximum likelihood (ML) methods collapse to OLS estimation when the same regressors appear in each equation, all of the parameter estimates are best linear unbiased (Kmenta, 1971; Bewley, 1986; Theil, 1971). Furthermore, the ratio of the OLS estimate to its standard error, given by the square root of the relevant diagonal element of

$$\Sigma_{\mathbf{OLS}} \otimes (\mathbf{X}'\mathbf{X})^{-1}, \tag{3.49}$$

is *t*-distributed. Note that the standard errors produced in the ML procedure are biased since $\Sigma_{\mathbf{ML}}$ is formed using the divisor T rather than (T - k) (where $k = k_1 = \ldots = k_n$ given the regressors are the same for each equation) (Bewley, 1986). In this study, the same regressors appear in each equation in models (3.41) and (3.42). Therefore, the OLS, GLS, and ML estimators are expected to be identical for models (3.41) and (3.42).

However, in addition to the correlation of disturbances between equations in the system, some linear constraints -- such as homogeneity and symmetry of parameters -- also exist in the systems (3.41) and (3.42). If there are q such linear restrictions in this system, and they can be written in matrix notation as

$$R\beta = r, \tag{3.50}$$

where **r** is known q-element vector; R is a known matrix of full row rank of an order (q x k). Then, the best linear unbiased constrained GLS coefficient estimator is

$$\begin{aligned} &\beta^{*}_{GLS} = \beta_{GLS} + CR'(RCR')^{-1}(r - R\beta_{GLS}), \\ &\text{where} \\ &C = (X'\Omega^{-1}X)^{-1} \quad \text{and} \\ &\beta_{GLS} = CX'\Omega^{-1}y = [X'(\Sigma^{-1} \otimes I)X]^{-1}X'(\Sigma^{-1} \otimes I)y, \end{aligned} \tag{3.51}$$

with the variance-covariance matrix

$$Var(\beta_{GLS}{}^{*}) = [C - CR'(RCR')^{-1}RC]. \tag{3.52}$$

The models expressed in equations (3.41) and (3.42) are allocation models. An allocation model is a system of equations purporting to explain the distribution of a predetermined aggregate among its components. The system must satisfy the constraint that the sum of the individual components equals the aggregate. In consumer demand, total expenditure is distributed among various goods, depending on their prices. The common theme that links all allocation models is the existence of an overriding identity that ensures the sum of the components equals the predetermined aggregate. Since the data for an allocation model naturally obey this identity, the implication for model specification is that the components predicted or implied by the model exactly sum to the predetermined aggregate. This rule, which governs the specification of an allocation model is known as the adding-up criterion. That is, in the levels versions of the Rotterdam models (3.41) and (3.42), the sum of the LHS, $w_i^{*}\log q_i$ ($i \in G_F$), equals the sum of RHS, $\log Q_F$.

Given the fact $\epsilon\iota = 0$ (Bewley, 1986) derived from the adding-up criterion, and from (3.48), one can derive that

$$\Sigma\iota = T^{-1}E(\epsilon'\epsilon)\iota = T^{-1}E(\epsilon'\epsilon\iota) = 0, \tag{3.53}$$

where **0** is an n x 1 null vector. This identity demonstrates that the disturbance covariance matrix is singular. Since Σ is singular, neither the generalized least squares (GLS) nor the maximum likelihood (ML) estimation can be applied to the full system in the usual manner.

In order to compute GLS or ML estimates, it is necessary either to delete one equation before estimation (the estimates for the omitted equation can be derived from the adding-up restriction) or to modify the estimator. If the omitted equation contains all of the regressors in the system -- that is, a residual equation -- ML (Oberhofer and Kmenta, 1971) and GLS (Barten 1969; Schmidt, 1976) results from the subsystem estimator are compatible with the adding-up restrictions. Kmenta and Gilbert (1968) showed that an iterative procedure (call this procedure the iterative Zellner efficient method, IZEF), which can be used to obtain β_{GLS} in (3.51), commences with an estimate of the covariance matrix based on OLS at the beginning, which results in the Zellner's two-stage aitken estimates (ZEF, which is a generalized least-squares). Thereafter, the Zellner's two-stage aitken estimates of the regression coefficients can be used for calculating a new set of residuals leading to a new estimate of Ω. In essence, the first step of IZEF is GLS (or ZEF) and the converged value is ML. All of the steps in IZEF are equally efficient in an asymptotic sense and the small sample properties of the estimators have not yet been fully explored. Since the GLS (or ZEF) estimates are asymptotically efficient while the ordinary least-squares estimates are not, one would expect the IZEF estimates to be superior to GLS (or ZEF) estimates.

Therefore, models (3.41) and (3.42) can be estimated with both homogeneity and symmetry restrictions using the IZEF procedure. If iterated seemingly unrelated least squares is adopted as the estimation method; upon convergence, the obtained maximum likelihood parameters are invariant, regardless to which share equation is dropped.

Data

Data Problems

Demand systems estimation increasingly makes use of household-level microdata. As analyzing the household-level microdata, a problem usually arises when the sample contains observations in which expenditures on one or more goods are zero. Although the economic and statistical theory underlying the estimation of systems of demand function is well-developed, no standard method has developed to solve this problem.

Household food consumption data collected in the 1987-88 National Food Consumption Survey (NFCS) are used in this study. The sample of the 1987-88 NFCS has a total of 4,273 observations (the number of housekeeping households -- there are 4,495 households recorded in the data set, and it has been suggested that only the housekeeping households be used for analytical studies); among these observations, 118 had zero consumption either in one or more food groups. In other words, 2.8 percent of total observations had zero consumption.

Given the fact that not every household consumes something in every category and that demand is constrained to be nonnegative in an n-dimension, several studies have developed methods to deal with zero expenditures in demand estimation. Houthakker (1954) initially recognized the nonnegativity constraint and treated it as a special case of rationing. Wales and Woodland (1983) and Lee and Pitt (1986) explored the econometric implications of this constraint based upon the Kuhn-Tucker conditions for nonnegativity. Ransom (1987) pointed out the relationship between the Wales-Woodland model and the simultaneous equation/limited dependent variable model of Amemiya (1974). Heien and Wessells (1990) followed Lee's approach (1978) for the first-stage estimation and then used the inverse Mills

ratio to correct for selectivity bias in the share equations. Other models for dealing with the zero observations problem have been proposed by Deaton and Irish (1984); Kay, Keen, and Morris (1984); Keen (1986); and Blundell and Meghir (1987). These models are based on the discrepancy between observed expenditure and actual consumption.

Lee (1978) generalized the two-step Amemiya (1974) estimator into a simultaneous-equation model, which consists of observable continuous endogenous variables, unobservable latent endogenous variables with dichotomous indicators, and limited and censored dependent variables. The number of equations is arbitrary, and tobit, probit, and censored models are special cases of this general model. Lee showed that the two-stage estimators resulting from this procedure are asymptotically more efficient than the two-stage estimators proposed by Nelson and Olsen (1978) and Heckman (1978). In other words, Lee's two-stage estimator might be used in the case when the sample consists of a portion of zero consumption of one or more goods. However, one should note that Lee's model is not an allocation model and the Mills ratios in Lee's approach are assumed to be independent from one another. Therefore, if Lee's approach is used to estimate allocation models, some ad hoc specification problems might arise.

Wales and Woodland (1983) developed two models of consumer demand that explicitly allow expenditure on one or more goods to be zero for a significant proportion of a random sample. The first model is based upon the Kuhn-Tucker (1951) conditions for the maximization of a utility function subject to the budget constraints and assumes that preferences are random over the population. By assuming that preferences are random over the population, the density function for the consumption vector of an individual drawn from the population can be derived using the Kuhn-Tucker conditions directly. The second model

assumes that preferences are non-random and is an extension of a limited dependent variable model of the type developed by Tobin (1958) for the case of a single equation and by Amemiya (1974) for a set of equations. The second model corresponds more closely to the traditional approach to econometric estimation of systems of demand functions. An individual's observed consumption vector is assumed to be the sum of the utility-maximizing consumption vector, obtained without regard to nonnegativity constraints, and a vector of random disturbances which have a truncated distribution. This truncation allows the observed vector to involve zero expenditures on one or more goods.

Using the data on Australian meat consumption, Wales and Woodland employed a quadratic utility function for the Kuhn-Tucker approach and a Stone-Geary utility function for the Amemiya-Tobin approach to derive two demand models. Wales and Woodland concluded that the empirical results were not very sensitive to the models used. This is an expected outcome due to the fact that both methods involve the same degree of complexity in terms of estimation technique, for example, evaluation of the bivariate normal distribution function, in their case for three commodities, provides no basis for making a choice between them. Finally, they admitted that these two models are restricted to systems with a small number of goods because of computational complexity although they are theoretically applicable for any number of goods.

Lee and Pitts' approach (1986) uses virtual prices, which are dual to Kuhn-Tucker conditions, to select the set of goods consumed -- the demand regime -- and to transform binding nonnegativity constraints into nonbinding constraints. It has the advantage of permitting the use of indirect cost and utility functions, such as the translog, and the analytic decomposition of demand effects for goods at the nonnegativity limit.

The main theme of Lee and Pitts' (1986) study is that consumers choose commodities to consume as they perceive the virtual prices (reservation or shadow prices) of commodities to be greater than their market prices. Lee and Pitt proved that the Kuhn-Tucker conditions are equivalent to the consumer consumption decision that is governed by the virtual prices. Lee and Pitts' approach is theoretically appealing; the empirical implemention of their approach is however troubled by the computational complexity of maximizing the likelihood function. For example, in the case of the translog demand system, estimation would require numerical integration involving multiple probability distributions. The problem is somewhat simpler for the case of production. With a translog cost function or other, the linearity of the derived demand equations allows for the adding-up condition and normal errors. Estimation of a translog cost function with three inputs has accomplished by Lee and Pitt (1984). Evaluation of multiple integrals, even in the normal case, has currently only been accomplished for a small number of goods.

Heien and Wessells (1990) used a two-stage method to estimate the demand for 11 food categories. In the first stage, a probit regression was computed that determines the probability that a given household will consume the good in question. This regression was then used to compute the inverse Mills ratio for each household. The inverse Mill ratio was later used as an instrument that incorporates the censoring latent variables in the second-stage estimation of the demand relations. In order to overcome the missing price problem, Heien and Wessells employed a procedure to estimate the missing prices. The procedure is involved in performing a regression with the data on the price as a function of regional dummies, seasonal dummies, and income. These regressions were then used to estimate the missing prices for those households that did not consume that particular item.

Several problems exist with Heien and Wessells' approach. First, the decision of whether to buy in the first stage was estimated as a single-equation probit model for individual commodities (Lee, 1978). Heien and Wessells ignored the interrelation of consumption decision among commodities. In other words, they assumed the covariance matrix of consumption decision equations are diagonal, which could result in inefficient estimates. Second, the specified demand relation in the second stage violates the adding-up criterion, which is an important feature of the allocation models. These misspecification problems may be severe, and inefficient estimates could be expected.

The approaches used by Wales and Woodland (1983) and Lee and Pitt (1986) are theoretically plausible; however, their empirical implications are limited to a small number of commodities (both Lee and Pitt and Wales and Woodland used three commodities) and simple utility functional forms as a result of the computational difficulty involving the multiple integrals under multivariate density functions. In this study, the computation is complicated by the five food categories or five non-linear equations (3.29) as well as the seven nutrients. On the other hand, even though Heien and Wessells' (1990) approach provides a method by which missing prices for the estimation of a demand system may be computed, there are missing nutrient variables in this study, which cannot be estimated when food items were not actually consumed.

The two demand models presented in equations (3.37) and (3.38) are complicated in many ways. First, the utility function of the levels version of the extended Rotterdam model (3.29) is difficult to derive. Therefore, the approaches used in the Lee and Pitt study and in the Wales and Woodland study cannot be used. In the Heien and Wessells study, the only missing observations are price variables. The missing price variables can be estimated and

incorporated into the demand parameter estimation. This study faces not only missing prices but also zero nutrient observations. In the levels version of the Rotterdam model all variables are defined in terms of logarithm, and zero values are not defined. Therefore, the limited-dependent variables techniques developed in previous studies cannot be incorporated into this study. As a result, observations with missing prices and zero nutrient observations were deleted from the sample, and the IZEF estimation method was used in the estimation of the levels Rotterdam model.

Data Summary

The data set used in this study is from the 1987-88 Nationwide Food Consumption Survey (NFCS). This USDA survey covers the period from April 1987 through the first week of August 1988. The 1987-88 NFCS is one of the most recent of many USDA food consumption studies. The survey is used now, as in the past, to describe food consumption behavior patterns and to assess the nutritional content of diets for their implications for policies relating to food production and marketing, food safety, food assistance, and nutrition education. In the 1987-88 NFCS, nationwide measurements of nutrient contents in each food item are reported and the amount of nutrients in each consumed food item may be obtained.

However, given the low response rate (35 percent), some have expressed concern as to how representative of this data set is (FASEB, 1991; GAO, 1991; USDA, 1991). Research comparing the demographic characteristics of the NFCS survey data to the Census Bureau's Current population survey found that inner-city residents, high-income households, and households with female heads are were significantly under-represented (GAO, 1991). Given that the consumption patterns of these groups differ from the population as a whole,

the parameter estimates will be biased (GAO, 1991; USDA, 1991). Nevertheless, this bias appears to be small. Murphy et al. (1992) adjusted the sample weights of each individual in the survey in order to cause the sample characteristics to mimic those in the U.S. population as a whole. Forcing the sample to be representative of the population, Murphy et al. (1992) demonstrated that the resulting parameter estimates "showed little difference . . ." from the estimates obtained with the original, nonrepresentative sample. Furthermore, comparing the results of their study to estimates obtained using a different cross-sectional data set, the 1986 Continuing Survey of Food Intakes by Individuals (CSFII) also showed very little difference for overlapping age/sex categories. Therefore, although the 1987-88 NFCS though has the potential for sampling bias, the bias is believed to be no greater than that of other, comparable household-level data sets.

In this study, food items are grouped into five food categories: dairy; meats and other protein food items; vegetables and fruit; grain products; and other (fats and oils, sugar and sweets, and other miscellaneous). Seven nutrients are considered: carbohydrates; fats and oils; proteins; vitamin group I (vitamins measured in milligrams, vitamins C and B-6, thiamin, riboflavin, and niacin); vitamin group II (measured in micrograms, folate, and vitamin B-12); digestible fibers; and minerals (calcium, phosphorus, magnesium, iron, zinc, copper, sodium, and potassium). The separation of vitamins by their measurement units is for the purpose of estimation.

Table 3-1 shows the sample statistics of the entire sample (4,237 observations, that is, Full Sample in Table 3-1) and the sample used in this study (4,155 observations, that is, Truncated Sample in Table 3-1). Comparing the sample used to the entire sample, the mean difference between these two samples, in percentage, varies from 0.36 percent for the number

Table 3-1. The Data Comparison between the Full Sample and Truncated Sample from the 1987-88 NFCS.

Variables		Full Sample		Truncated Sample		Difference			
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	%	Std. Dev.	%
Quantity of Dairy (pounds)	q_1	20.27	17.63	20.64	17.65	-0.372	-1.84	-0.019	-0.11
Quantity of Meats (pounds)	q_2	12.99	9.99	13.12	10.00	-0.134	-1.03	-0.010	-0.10
Quantity of Veg. and Fruit (pounds)	q_3	23.89	17.46	24.24	17.38	-0.347	-1.45	0.073	0.42
Quantity of Grains (pounds)	q_4	5.09	4.26	5.17	4.26	-0.081	-1.60	-0.002	-0.05
Quantity of Others (pounds)	q_5	9.51	10.96	9.67	11.02	-0.162	-1.71	-0.057	-0.52
Value of Dairy (dollars)	V_1	7.49	6.20	7.63	6.18	-0.134	-1.79	0.016	0.26
Value of Meats (dollars)	V_2	21.16	16.06	21.40	16.12	-0.245	-1.16	-0.057	-0.36
Value of Veg.& Fruit (dollars)	V_3	12.44	8.77	12.62	8.75	-0.185	-1.49	0.017	0.20
Value of Grains (dollars)	V_4	10.02	8.10	10.19	8.11	-0.173	-1.73	-0.018	-0.22
Value of Others (dollars)	V_5	9.99	9.64	10.18	9.68	-0.187	-1.87	-0.042	-0.44
# of Family Members in Age Group 1	AG_1	0.34	0.69	0.35	0.69	-0.006	-1.92	-0.005	-0.70
# of Family Members in Age Group 2	AG_2	0.27	0.61	0.28	0.62	-0.004	-1.51	-0.004	-0.72
# of Family Members in Age Group 3	AG_3	0.26	0.60	0.26	0.60	-0.001	-0.58	-0.001	-0.15
# of Family Members in Age Group 4	AG_4	1.09	0.96	1.10	0.96	-0.010	-0.87	-0.002	-0.22
# of Family Members in Age Group 5	AG_5	0.52	0.77	0.53	0.77	-0.003	-0.54	-0.002	-0.24
# of Family Members in Age Group 6	AG_6	0.31	0.61	0.31	0.61	0.001	0.36	-0.001	-0.14
Household Size	HZ	2.78	1.44	2.81	1.44	-0.023	-0.83	0.001	0.10
Household Income (dollars)	INC1	27,287.59	23,497.81	27,528.91	23,612.60	-241.320	-0.88	-114.790	-0.49
Carbohydrates in Dairy (grams)	x_{11}	486.61	443.38	496.02	444.26	-9.413	-1.93	-0.873	-0.20
Carbohydrates in Meats (grams)	x_{21}	168.63	214.47	170.46	215.02	-1.834	-1.09	-0.551	-0.26
Carbohydrates in Veg. & Fruit (grams)	x_{31}	1,161.75	846.73	1,179.16	841.08	-17.410	-1.50	5.642	0.67
Carbohydrates in Grains (grams)	x_{41}	2,136.52	1,734.27	2,171.77	1,735.24	-35.250	-1.65	-0.970	-0.06
Carbohydrates in Others (grams)	x_{51}	1,191.18	1,250.84	1,216.68	1,256.03	-25.500	-2.14	-5.190	-0.41
Fats and Oils in Dairy (grams)	x_{12}	324.75	290.40	331.04	290.77	-6.288	-1.94	-0.361	-0.12
Fats and Oils in Meats (grams)	x_{22}	950.79	789.00	961.11	791.29	-10.321	-1.09	-2.284	-0.29
Fats and Oils in Veg. & Fruit (grams)	x_{32}	81.55	105.01	83.19	105.77	-1.639	-2.01	-0.756	-0.72
Fats and Oils in Grains (grams)	x_{42}	237.57	209.86	241.98	210.51	-4.407	-1.86	-0.651	-0.31

Table 3-1. Continued.

Variables		Full Sample		Truncated Sample		Difference			
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	%	Std. Dev.	%
Fats and Oils in Others (grams)	x_{25}	556.59	588.71	568.29	591.19	-11.708	-2.10	-2.480	-0.42
Proteins in Dairy (grams)	x_{13}	329.30	277.69	335.27	277.85	-5.975	-1.81	-0.154	-0.06
Proteins in Meats (grams)	x_{23}	890.11	673.83	899.49	673.95	-9.381	-1.05	-0.124	-0.02
Proteins in Veg. & Fruit (grams)	x_{33}	120.87	88.09	122.70	87.70	-1.831	-1.52	0.393	0.45
Proteins in Grains (grams)	x_{43}	301.41	236.96	306.41	237.19	-4.997	-1.66	-0.236	-0.10
Proteins in Others (grams)	x_{53}	24.80	27.94	25.31	28.10	-0.508	-2.05	-0.164	-0.59
Vitamin Group I in Dairy (milligrams)	x_{14}	107.80	158.45	109.63	158.97	-1.830	-1.70	-0.520	-0.33
Vitamin Group I in Meats (milligrams)	x_{24}	385.34	310.54	389.79	310.94	-4.452	-1.16	-0.396	-0.13
Vitamin Group I in Veg. & Fruit (milligrams)	x_{34}	1,971.69	1,617.37	2,000.45	1,617.92	-28.760	-1.46	-0.550	-0.03
Vitamin Group I in Grains (milligrams)	x_{44}	388.10	408.10	393.95	407.75	-5.850	-1.51	0.350	0.09
Vitamin Group I in Others (milligrams)	x_{54}	238.11	584.79	242.43	590.40	-4.318	-1.81	-5.609	-0.96
Vitamin Group II in Dairy (micrograms)	x_{15}	458.96	451.08	466.52	448.95	-7.557	-1.65	2.131	0.47
Vitamin Group II in Meats (micrograms)	x_{25}	933.65	1,012.80	944.34	1,017.50	-10.694	-1.15	-4.700	-0.46
Vitamin Group II in Veg. & Fruit (micrograms)	x_{35}	1,954.33	1,535.90	1,983.05	1,537.34	-28.720	-1.47	-1.440	-0.09
Vitamin Group II in Grains (micrograms)	x_{45}	2,008.04	2,023.79	2,039.55	2,027.24	-31.510	-1.57	-3.450	-0.17
Vitamin Group II in Others (micrograms)	x_{55}	255.06	753.21	260.34	762.02	-5.281	-2.07	-8.806	-1.17
Digestible Fibers in Dairy (grams)	x_{16}	2.45	7.65	2.50	7.73	-0.051	-2.08	-0.078	-1.02
Digestible Fibers in Meats (grams)	x_{26}	37.88	67.77	38.23	67.89	-0.348	-0.92	-0.114	-0.17
Digestible Fibers in Veg. & Fruit (grams)	x_{36}	138.66	103.79	140.64	103.58	-1.982	-1.43	0.209	0.20
Digestible Fibers in Grains (grams)	x_{46}	119.73	96.51	121.65	96.61	-1.921	-1.60	-0.091	-0.09
Digestible Fibers in Others (grams)	x_{56}	9.98	20.87	10.20	21.08	-0.212	-2.13	-0.206	-0.99
Minerals in Dairy (milligrams)	x_{17}	40,318.20	34,379.19	41,060.76	34,399.30	-742.560	-1.84	-20.110	-0.06
Minerals in Meats (milligrams)	x_{27}	38,994.70	29,341.00	39,430.64	29,372.49	-435.940	-1.12	-31.490	-0.11
Minerals in Veg. & Fruit (milligrams)	x_{37}	36,400.16	26,417.95	36,993.98	26,301.89	-593.820	-1.63	116.060	0.44
Minerals in Grains (milligrams)	x_{47}	34,445.19	28,199.94	35,036.05	28,272.74	-590.860	-1.72	-72.800	-0.26
Minerals in Others (milligrams)	x_{57}	12,909.21	11,068.68	13,164.44	11,063.30	-255.230	-1.98	5.380	0.05

Table 3-1. Continued.

Variables		Full Sample		Truncated Sample		Difference			
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	%	Std. Dev.	%
Total Number of Meals (in 0.01 meals)	z_8	4,792.26	2,649.34	4,836.56	2,648.31	-44.300	-0.92	1.030	0.04

Std. Dev. is the abbreviation for stand deviatio, and Veg. is the abbreviation for vegetables. $x_{11} + x_{21} + x_{31} + x_{41} + x_{51} = z_1$; $x_{12} + x_{22} + x_{32} + x_{42} + x_{52} = z_2$; $x_{13} + x_{23} + x_{33} + x_{43} + x_{53} = z_3$; $x_{14} + x_{24} + x_{34} + x_{44} + x_{54} = z_4$; $x_{15} + x_{25} + x_{35} + x_{45} + x_{55} = z_5$; $x_{16} + x_{26} + x_{36} + x_{46} + x_{56} = z_6$; $x_{17} + x_{27} + x_{37} + x_{47} + x_{57} = z_7$.

of family members in age group 6 (Ag_6) to 2.14 percent in absolute value for carbohydrates embodied in the other food category (x_{51}), and their associated standard error difference are 0.14 and 0.41 percent in respective absolute values. Therefore, the whole sample considered to not contain a significant portion of zero consumption of one or more food categories. Consequently, the discard of those zero consumption observations is expected not to cause significant bias theoretically in terms of estimation. Therefore, given this nature of the data set, the theoretical problems stated above from existing literature, and the functional forms of the two models considered here, a decision of deleting zero consumption observations is made for estimation of models (3.41) and (3.42).

A sample of 4,155 observations or households is used to estimate models (3.41) and (3.42). Summary statistics of the data are shown in Table 3-1. An average household with 2.81 persons consumed 20.64, 13.12, 24.24, 5.17, and 9.67 pounds per week of dairy products, meats and other protein source products, vegetables and fruit, grains, and all other foods, respectively. Their respective expenditures are $7.63, $21.40, $12.62, $10.19, and $10.18. Table 3-1 also shows the individual nutritional contents in the five food groups considered. For example, there are 496, 170, 1,179, 2,172, and 1,217 pounds of carbohydrates in dairy products, meats and other protein source products, vegetables and fruit, grains, and all other foods, respectively.

Table 3-2 shows a comparison of the daily food consumed by individuals in the 1987-88 NFCS to that recommended by USDA (1992). Among the four food groups (not counting the Others group), dairy -- with an average actual intake of 2.1 servings -- is the only group in which individual intakes are within the recommended range. (The recommended servings are 2-3 for dairy). Individuals in this survey ate more high-protein food items (3.6-5.4 for

Table 3-2. A Comparison of the Daily Food Intakes between Actual Serving Size Consumed and Recommended.

Food Quantity	Serving Size	
	Actual[a]	Recommended[b]
Dairy	2.1[c]	2-3
Meats	3.6-5.4[d]	2-3
Veg. & Fruit	2.5-4.9[e]	5-9[f]
Grains	4.2[g]	6-11
Others	NA	Sparingly

[a] Calculated based upon the 1987-88 NFCS.
[b] Recommended by USDA (The Food Guide Pyramid, 1992).
[c] Calculated by a serving size of 8 ounces.
[d] Calculated by serving sizes between 3 ounces and 2 ounces.
[e] Calculated by serving sizes of 8 ounces and 4 ounces.
[f] Represents a sum of serving sizes of vegetables and fruit.
[g] Calculated by a serving size of one ounce.
NA represents an unknown quantity due to the lack of recommended serving sizes.
Veg. is the abbreviation for vegetables.

actual versus 2-3 for the recommended), and less vegetables & fruit (2.5-4.9 for actual versus 5-9 for the recommended although servings of fruit and vegetables are not reported individually to allow comparison to recommendation for these two food groups) and grains (4.2 for actual versus 6-11 for the recommended) than the recommended amounts. In other words, if the survey reflected how individuals consumed their food for the U.S. population, nutrition education appears to be needed to promote the increased consumption of fruit, vegetables, and grains, and food-related policy and food assistance programs might also need to be directed toward more grains, vegetables, and fruit. Nevertheless, one can argue that this survey was made about nine years ago, and that this survey was confined to home food supply. That is, the data for dining-out are not available, and thus, the data do not reflect the whole picture of food consumption.

Sources of Nutrients

The USDA classifies foods into five groups: dairy products, meats and other protein foods, fruit, vegetables, and grain. According to the Food Guide Pyramid (USDA, 1992) as shown in Figure 3-1, each of these food groups provides some, but not all, of the nutrients that individuals need. Foods in one group cannot be replaced by those in another. For a healthy diet, one particular food group is not more important than another; an individual needs them all. The second level from the top of the Pyramid are two groups of foods that come mostly from animals: milk, yogurt, and cheeses (dairy products); and meat, poultry, fish, dry beans, eggs, and nuts (meats and other protein foods). These foods are important sources of protein, calcium, iron, and zinc. The next lower level includes foods that come from plants: vegetables and fruit. They provide vitamins, minerals, and fiber. The bottom level of

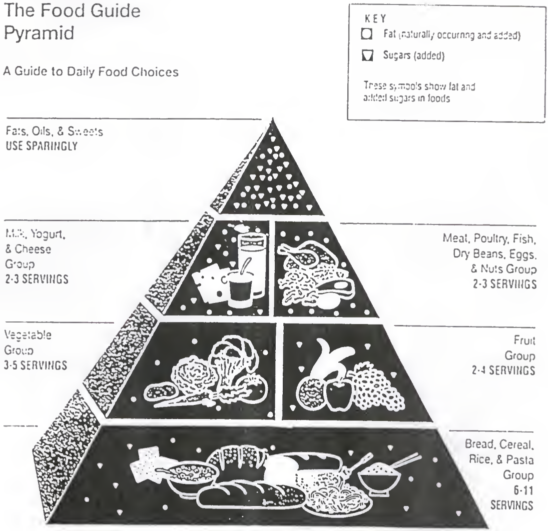

Figure 3-1. The Food Guide Pyramid.

the food Pyramid are breads, cereals, rice, and pasta -- all foods from grains. They are good sources of carbohydrates, fiber, vitamins, and minerals. Individuals need the most servings of these foods each day. Fats and oils such as salad dressings and oils, cream, butter, margarine, sugars, soft drinks, candies and sweet desserts, are on the top of the Pyramid. These foods provide calories and little else nutritionally; thus, individuals are advised to use them sparingly. For a daily balanced diet, it is recommended that 2-3 servings of dairy products; 2-3 servings of meats and other protein products; 3-5 servings of vegetables; 2-4 servings of fruit, and 6-11 servings of grain products be consumed (USDA, 1992). The variations in serving sizes are due to individual differences in nutrient needs. In general, most older adults and sedentary women need about 1,600 calories a day; most children, teen-aged girls, active women, and many sedentary men need about 2,200 calories a day; and teenage boys, many active men, and some active women need about 2,800 calories a day (USDA, 1992). The units of servings for various foods are different: for example, milk, juice, vegetables, and cereal are served in cups; meats are in ounces; and bread, and fruit are served by their own units (USDA, 1992).

Fats and oils, carbohydrates, and proteins provide energies in terms of calories. One gram of fats and oils produce nine calories, while both carbohydrates and proteins yield four calories per gram. The Dietary Guidelines (USDA, 1995) recommend that Americans limit fat intake in their diets to 30 percent of their calorie intake, while limiting sugar intake to about 6-18 teaspoons according to the different daily required calories (for example, 6 teaspoons a day if one eats about 1,600 calories, 12 teaspoons at 2,200 calories, or 18 teaspoons at 2,800 calories) (USDA, 1992). About four percent of body weight is made up of elements called minerals that are crucial to the body's metabolism. Vitamins, a group of

potent organic compounds that occur in minute quantities in foods, are essential for some specific body functions of maintenance and growth. Proteins are primarily found in meats, beans, and dairy; carbohydrates exist in all varieties of foods except meats; and fats and oils are in dairy products, meats, nuts, some desserts and sweets, and in fat added to low-fat foods like vegetables; fiber is found only in plant foods, such as whole-grain breads and cereals, beans and peas, and other vegetables and fruit; vitamins and minerals are found in all of the five basic food groups, with different foods offering different nutrients (University of Florida, 1971). Eating a variety of fiber-containing plant foods is important for proper bowel function; can reduce symptoms of chronic constipation, diverticular disease, and hemorrhoids; and may lower the risk for heart disease and colorectal cancer. However, some of the health benefits associated with a high-fiber diet may come from other components present in these foods, not just from fiber itself. For this reason, fiber is best obtained from foods rather than supplements (USDA, 1995).

Results

Since the objective of this study is to investigate the effect of nutrients on consumer food demand, models (3.41) and (3.42) are derived to serve this purpose; however, a basic procedure of model selection must be performed before any meaningful estimation can be conducted. That is, the extended levels version of the Rotterdam models (3.41) or (3.42) must be compared to a basic levels version of the Rotterdam model that only has price and income variables. The likelihood ratio test (LRT) for model selection is

$$LRT = -2(\log L(\theta^{*}) - \log L(\theta)), \tag{3.54}$$

where θ^* is the vector of parameter estimates of the basic levels version of the Rotterdam model; θ is the vector of parameter estimates of the extended levels version of the Rotterdam model (that is, either (3.41) or (3.42)); and $L(\cdot)$ is the log value of the likelihood function (Amemiya, 1985). That is, under the null hypothesis that the basic levels version of the Rotterdam model describes the data best, test statistic LRT has an asymptotic $\chi^2(q)$ distribution in which q is the number of restrictions imposed (that is, the degrees of freedom equal to the difference between the number of parameters in the basic and the extended levels version of the Rotterdam model). The LRT for model selection between the basic levels version of the Rotterdam model and (3.41) or (3.42) is 1,911.84, an indication that nutrients have significant impacts on the demand for food groups examined in this study.

In models (3.41) and (3.42), *i*, and *j* denote the food group in question, and *h* denotes the nutrients in question. There are three, three, five, five, and three own-nutrient variables defined in the demand equations for dairy, meats, vegetable and fruit, grain, and others, respectively. This construction is due to the nutritional nature of the five food groups: that is, fats and oils, proteins, and minerals are contained in both dairy and meats groups; carbohydrates, vitamin groups I & II, fibers, and minerals are embodied in the vegetable and fruit and grains groups; while carbohydrates, fats and oils, and minerals exist in the other group.

The dependent variables, q_is, are the amounts consumed by the household per meal equivalent -- that is, the quantities consumed by the household divided by the total number of meals eaten by household members. Nutrient contents, x_{jh}s, are defined as the average nutrients per unit of food consumed -- that is, the total amount of nutrient divided by the quantity of the food consumed.

Table 3-3 shows the parameter estimates of α^{*}_{i0}, μ^{*}_{i}, π^{*}_{ij}, and γ^{*}_{ijh} in model (3.41). Note that these are conditional estimates. In other words, these parameters are estimates for the food demand subsystem (Theil, 1980), which are conditioned on how total budget is allocated to broad commodity groups, including the food group. All expenditure parameter estimates (μ^{*}_{i}) are positive and less than unity; all own-price parameter estimates (π^{F*}_{ii}, i = 1, . . ., 5) are negative; and cross-price parameter estimates (π^{F*}_{ij}, i, j = 1, . . ., 5) are positive, indicating substitution relationship. All expenditure and price estimates are significantly different from zero at $\alpha = 0.05$ level, given that these estimates are at least two times greater than their respective standard errors.

The results reported in Table 3-3 also show that nutrients have either positive or negative impacts on the demand for the five food groups examined in this study. Of the total 19 own-nutrient parameter estimates (γ^{*}_{iih}), 13 are positive and six are negative, and 17 are significantly different from zero at $\alpha = 0.05$ level. The positive parameter estimates indicate that increases in nutritional contents will increase the consumption of the food in question, and the negative parameter estimates indicate a decrease in consumption of the food in question. Own-nutrient parameter estimates (γ^{*}_{iih}) show that all three nutrients have positive impacts on the demand for the dairy group. Protein and mineral contents in the meat group increase the demand for meat items, and the fat content in the meat group decreases the demand for meats. Folate and vitamin B-12 together, or vitamin II, and mineral contents in vegetables and fruit have positive impacts on the demand for vegetables and fruit; however, the carbohydrate and the vitamin group I have negative impacts on the demand for vegetables and fruit. The impact of fiber contents in vegetables and fruit is positive but not statistically different from zero. Results also show that folate, vitamin B-12, and mineral contents in

Table 3-3. Estimation of the Levels Version of the Rotterdam Model, Equation (3.41).

Food Groups	Intercept	Log Q_F	log p_1 (Dairy)	log p_2 (Meats)	log p_3 (Veg. & Fruit)	log p_4 (Grains)	log p_5 (Others)
Dairy	-2.2157*	0.1395*	-0.3662*	0.2085*	0.0145	0.0787*	0.0645*
	(0.3972)	(0.0109)	(0.0137)	(0.0134)	(0.0117)	(0.0105)	(0.0099)
Meats	-2.0742*	0.2646*		-1.0184*	0.2975*	0.3322*	0.1801*
	(0.7120)	(0.0197)		(0.0269)	(0.0158)	(0.0155)	(0.0154)
Veg. & Fruit	-2.2582*	0.0318*			-0.5266*	0.1285*	0.0861*
	(0.4745)	(0.0129)			(0.0186)	(0.0125)	(0.0119)
Grains	3.6747*	0.4223*				-0.6444*	0.1050*
	(0.4947)	(0.0134)				(0.0161)	(0.0113)
Others	2.8734*	0.1419*					-0.4357*
	(0.5440)	(0.0151)					(0.0158)

Food Groups	Dairy	Meats	Veg. & Fruit	Grains	Others
Dairy					
Protein	0.0938*	-0.0189	-0.1702*	0.1842*	-0.0890
	(0.0372)	(0.0665)	(0.0108)	(0.0452)	(0.0508)
Fats	0.0413*	-0.0623*	0.0595*	0.0009	-0.0395*
	(0.0094)	(0.0161)	(0.0450)	(0.0110)	(0.0123)
Minerals	0.4136*	-0.2096*	0.0218	-0.0755	-0.1503*
	(0.0383)	(0.0682)	(0.0396)	(0.0465)	(0.0522)
Meats					
Protein	-0.0579	0.3229*	-0.1928*	0.0076	-0.0798
	(0.0332)	(0.0605)	(0.0175)	(0.0408)	(0.0460)
Fats	-0.0209	-0.0615*	0.0563*	0.0616*	-0.0354
	(0 0147)	(0.0267)	(0.0218)	(0.0181)	(0.0204)
Minerals	-0.1061*	0.5816*	-0.07060*	-0.2663*	-0.1386*
	(0.0183)	(0.0333)	(0.0268)	(0.0225)	(0.0253)
Veg. & Fruit					
Carbohydrates	-0.0544*	0.1826*	-0.0529*	-0.1346*	0.0593
	(0.0225)	(0.0408)	(0.0178)	(0.0277)	(0.0312)
Vitamin I	-0.0020	0.1134*	-0.1623*	-0.0022	0.0531*
	(0.0150)	(0.0272)	(0.0195)	(0.0185)	(0.0208)
Vitamin II	0.0257	-0.1671*	0.1044*	0.0379	-0.0009
	(0.0163)	(0.0296)	(0.0197)	(0.0201)	(0.0227)
Fibers	0.0368*	-0.0953*	0.0026	0.0004	0.0555*
	(0.0162)	(0.0292)	(0.0239)	(0.0199)	(0.0223)
Minerals	0.0319	-0.1112*	0.3366*	-0.0561*	-0.2012*
	(0.0201)	(0.0364)	(0.0442)	(0.0247)	(0.0278)

Table 3-3. Continued.

Food Groups	Dairy	Meats	Veg. & Fruit	Grains	Others
Grains					
Carbohydrates	0.0069 (0.0372)	-0.1652* (0.0662)	0.1304* (0.0138)	0.0166 (0.0470)	0.0113 (0.0505)
Vitamin I	-0.0217 (0.0116)	0.0635* (0.0210)	0.0441* (0.0136)	-0.1226* (0.0144)	0.0367* (0.0160)
Vitamin II	-0.0312* (0.0114)	-0.0111 (0.0208)	-0.0512* (0.0158)	0.0933* (0.0141)	0.0002 (0.0159)
Fibers	-0.0195 (0.0133)	0.2231* (0.0158)	-0.1236* (0.0164)	-0.0416* (0.0164)	-0.0384* (0.0184)
Minerals	-0.0108 (0.0183)	-0.0538 (0.0219)	0.0503* (0.0231)	0.1249* (0.0231)	-0.1108* (0.0251)
Others					
Carbohydrates	-0.0119* (0.0046)	-0.0316* (0.0055)	-0.0015 (0.0056)	-0.0260* (0.0056)	0.0710* (0.0064)
Fats	0.0000*[a] (0.0000[b])	0.0001* (0.0000[b])	0.0001* (0.0000[b])	0.0001* (0.0000[b])	-0.0002* (0.0000[b])
Minerals	-0.0346* (0.0071)	-0.0686* (0.0084)	-0.0976* (0.0085)	-0.0263* (0.0085)	0.2271* (0.0102)

Numbers in parentheses are the corresponding standard deviations.
Veg. is the abbreviation for vegetables.
* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.
[a] Denotes a value of 0.00003.
[b] Denotes a value of 0.00001.

grains increase the demand for grains and that fiber and vitamin I contents decrease the demand for grains. The own-nutrient impact of carbohydrate contents in grains is positive but statistically insignificant. The negative impact of the vitamin group I on the demand for vegetables and fruit as a group and grains may be caused by the way that this vitamin group is created, that is, the sum of five different vitamins (vitamin C, vitamin B-12, thiamin, riboflavin, and niacin). The results for the other group show that carbohydrate and mineral contents increase the demand for the other food group and that fat contents decrease the demand for the other food group.

Both positive and negative cross-nutrient parameter estimates (γ_{ijh}^{*}) are reported in Table 3-3. Since food items can be used in combinations to produce different dishes, the upper limits for nutrients in a meal are difficult to set. For example, milk (dairy group) and cereals (grain group) are used together for breakfast. In this case, the increase in dairy protein could increase the demand for the grain group, given the cross-nutrient parameter estimate is greater than zero (0.18). On the other hand, the increase in meat protein reduces the demand for dairy products given the cross-nutrient parameter estimate is -0.06. As a result, cross-nutrient parameter estimates across food groups could be positive or negative, depending on how each food item is used, making the interpretation of these cross-nutrient estimates difficult.

Conditional expenditure elasticities, compensated and uncompensated price elasticities, and nutrient elasticity estimates can be derived as

$$\text{expenditure elasticity: } \eta_{im} = \mu_i^{*} / w_i^{*}, \quad i = 1, \ldots, 5; \tag{3.55}$$

$$\text{compensated price elasticity: } \epsilon_{ij} = \pi^*_{ij}/w^*_i, \quad i = 1,\ldots,5; \tag{3.56}$$

$$\text{uncompensated price elasticity: } \eta_{ij} = \epsilon_{ij} - w^*_j \eta_{im}, \quad i,j = 1,\ldots,5; \tag{3.57}$$

and

$$\text{nutrient elasticity: } \epsilon_{ijh} = \gamma^*_{ijh}/w^*_i, \quad i,j = 1,\ldots,5;\ h \in j. \tag{3.58}$$

Expenditure elasticity (η_{im}) measures the percentage change on the consumption of one food group in question, given a percentage change of food expenditure. Compensated and uncompensated price elasticity (ϵ_{ij} and η_{ij}) measures the percentage change on the consumption of food group *i*, given a percentage change of p_j for the unchanged utility level and the unchanged food expenditure, respectively. The own-nutrient demand elasticity (ϵ_{iih}) shows the percentage change in the demand for food group *i* due to a 1 percent change in one of the nutrients found in food group *i*, while the cross-nutrient demand elasticity (ϵ_{ijh}) shows the percentage change in the demand for food group *i* due to a 1 percent change in nutrients found in food group *j*.

These elasticity estimates are derived at sample means and presented in Table 3-4. All own-price demand elasticity estimates are negative, and their absolute values are greater than one. The compensated (uncompensated) own-price elasticity estimates range from 2.48 (2.51) for vegetables and fruits as a group and to 3.92 (4.34) for grains. This reveals that demand for every individual food group considered is very elastic with respect to its own price; that is, the consumption of an individual food group decreases more than 1 percent as its price increases by 1 percent. All cross-price demand elasticity estimates (ϵ_{ij} and η_{ij}) are positive and small in comparison to own-price demand elasticity estimates.

Table 3-4. Conditional Demand Elasticity Estimates Calculated at Sample Means.

	Dairy	Meats	Veg. & Fruit	Grains	Others
	Compensated Price Elasticity				
Dairy	-2.9400*	0.6150*	0.0681	0.4783*	0.4049*
Meats	1.6741*	-3.0034*	1.4008*	2.0190*	1.1298*
Veg. & Fruit	0.1161	0.8775*	-2.4791*	0.7810*	0.5399*
Grains	0.6317*	0.9797*	0.6050*	-3.9162*	0.6584*
Others	0.5182*	0.5312*	0.4052*	0.6379*	-2.7331*
	Uncompensated Price Elasticity				
Dairy	-3.0796*	0.5178*	0.0495	0.1586*	0.2941*
Meats	1.2944*	-3.2680*	1.3502*	1.1488*	0.8281*
Veg. & Fruit	-0.1218	0.7118*	-2.5109*	0.2359*	0.3509*
Grains	0.4475*	0.8513*	0.5804*	-4.3386*	0.5120*
Others	0.3397*	0.4068*	0.3814*	0.2288*	-2.8750*
	Expenditure Elasticity				
Expenditure	1.1198*	0.7804*	0.1495*	2.5664*	0.8900*
Dairy	*Nutrient Demand Elasticity*				
Protein	0.7532*	-0.0556	-0.8012*	1.1194*	-0.5581
Fats	0.3318*	-0.1836*	0.2801*	0.0057	-0.2477*
Minerals	3.3200*	-0.6181*	0.1024	-0.4585	-0.9428*
Meats					
Protein	-0.4645	0.9524*	-0.9077*	0.0459	-0.5007
Fats	-0.1681	-0.1814*	0.2650*	0.3740*	-0.2220
Minerals	-0.8518*	1.7151*	-0.3324*	-1.6184*	-0.8692*
Veg & Fruit					
Carbohydrates	-0.4366*	0.5385*	-0.2490*	-0.8178*	0.3717
Vitamin (a)	-0.0159	0.3343*	-0.7639*	-0.0135	0.3332*
Vitamin (b)	0.2060	-0.4928*	0.4913*	0.2305	-0.0054
Fibers	0.2951*	-0.2809*	0.0120	0.0026	0.3483*
Minerals	0.2560	-0.3279*	1.5846*	-0.3409*	-1.2622*
Grains					
Carbohydrates	0.0557	-0.4873*	0.6141*	0.1007	0.0708
Vitamin I	-0.1741	0.1871*	0.2077*	-0.7449*	0.2301*
Vitamin II	-0.2501*	-0.0326	-0.2412*	0.5668*	0.0012
Fibers	-0.1563	0.6578*	-0.5820*	-0.2526*	-0.2409*
Minerals	-0.0864	-0.1586	0.2370*	0.7593*	-0.6947*
Others					
Carbohydrates	-0.0958 *	-0.0933*	-0.0069	-0.1578*	0.4454*
Fats	0.0003*	0.0003*	0.0003*	-0.0003*	-0.0010*
Minerals	-0.2777*	-0.2022*	-0.4596*	-0.1600*	1.4246*

* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.
Veg. is the abbreviation for vegetables.

Expenditure elasticity estimates indicate that if food expenditure is increased by 1 percent, the expenditure for dairy and grain groups would be increased by more than 1 percent ($\eta_{1m} = 1.12$; $\eta_{4m} = 2.57$), and the expenditures for the rest of the food groups would be increased by less than 1 percent ($\eta_{2m} = 0.78$; $\eta_{3m} = 0.15$; $\eta_{5m} = 0.89$).

Two types of nutrient demand elasticity estimates are presented in Table 3-4: own-nutrient demand elasticities and cross-nutrient demand elasticities. For example, if the fat content in the meats group is increased by 1 percent, the demand for dairy will be decreased by 0.17 percent; the demand for meats will be decreased by 0.18 percent; the demand for vegetables and fruit as a group will be increased by 0.27 percent; the demand for grains will be increased by 0.37 percent; and the demand for the other group will be decreased by 0.22 percent. Minerals are the common nutrients embodied in every food group. All own-nutrient elasticity estimates for minerals are positive and significantly different from zero, ranging from 0.76 for grains to 3.32 for dairy products. That is, the demand for grains will increase by 0.76 percent for a 1 percent increase in minerals found in grains, and the demand for dairy will increase by 3.32 percent for 1 percent increase in minerals embodied in dairy products.

In Table 3-4, both positive and negative cross-nutrient elasticities are reported. For example, cross-nutrient elasticities for minerals have both positive and negative signs, indicating that there are both substitution and complementary relationships existing between minerals found in one particular food group and the consumption of another food group. Because people eat different combinations of food items for meals, no specific interpretations will be given to the own-nutrient and cross-nutrient elasticities as the interpretations are only limited by one's imagination.

Note that these are conditional own-price elasticities, and the unconditional compensated price elasticity estimates, ϵ_{ij}^{u}, can be derived using the following relationship:

$$\epsilon_{ij}^{u} = \frac{\pi_{ij}}{w_i} = \frac{1}{w_i}\left(\pi_{ij}^{*} W_F + \phi\mu_i\mu_j\left(1/M_F - 1 \right)\right), \tag{3.59}$$

where π_{ij} is the unconditional Slutsky term (Theil, 1980) and w_i is the unconditional expenditure share on food. The food expenditure share for 1987-88 is 12 percent. The conditional compensated own-price elasticities, estimated with the 1987-88 food expenditure share, are between -0.30 and -0.47, which seem to be reasonable estimates. In order to derive the unconditional price elasticities, one needs additional parameters, such as ϕ, W_F, and M_F. Duffy (1987) demonstrated how to obtain these estimates and unconditional price parameters. Using the estimates of ϕ (= -0.625) and M_F (= 0.26) from Theil et al. (1989) and W_F (=0.12), the approximation of the unconditional price elasticity estimates can be obtained and are reported in Table 3-5. The unconditional expenditure elasticities ranged from 0.06 for vegetables and fruit as a group to 0.41 for dairy products; the unconditional compensated (uncompensated) own price elasticity estimates in absolute values ranged from 0.30 (0.30) for vegetables and fruit to 0.60 (0.62) for grains; and the unconditional compensated and uncompensated cross-price elasticity estimates are small in magnitude as compared to the own-price elasticities.

Recall that the specification of the levels version of the Rotterdam model (3.42) allows nutrient variables to affect the price perceived by consumers of the food group in question. Table 3-6 summarizes the impact of nutrients on perceived price. Columns 1-7 show the impacts of individual nutrients on perceived prices, and the last column shows the total impact of all nutrients on their respective perceived food prices.

Table 3-5. Unconditional Demand Elasticity Estimated Calculated at Sample Means.

	Dairy	Meats	Veg. & Fruit	Grains	Others
			Expenditure Elasticity		
Expenditure	0.4143	0.2887	0.0553	0.9496	0.3293
			Compensated Price Elasticity		
Dairy	-0.3664	0.1626	0.0095	0.0182	0.0423
Meats	0.0600	-0.3813	0.1012	0.0768	0.0498
Veg. & Fruit	0.0056	0.1618	-0.2954	0.0644	0.0457
Grains	0.0138	0.1578	0.0827	-0.5931	0.0320
Others	0.0332	0.1195	0.0609	0.0332	-0.3404
			Uncompensated Price Elasticity		
Dairy	-0.3764	0.1479	-0.0009	0.0109	0.0350
Meats	0.0564	-0.3970	0.0950	0.0724	0.0450
Veg. & Fruit	0.0049	0.1614	-0.3001	0.0640	0.0451
Grains	0.0002	0.1218	0.0595	-0.6170	0.0147
Others	0.0288	0.1076	0.0532	0.0276	-0.3503

Veg. is the abbreviation for vegetables.

Table 3-6. The Nutrient Impacts on Food Prices.

Food Prices	Nutrients							
	Carbohydrates (h = 1)	Fats & Oils (h = 2)	Proteins (h = 3)	Vitamin I (h = 4)	Vitamin II (h = 5)	Fibers (h = 6)	Minerals (h = 7)	Total
Dairy (j = 1)		1.3622* (0.0862)	2.0544* (0.0905)				5528.34 52* (2538.8709)	15718.3201 (13601.8669)
Meats (j = 2)		0.7743* (0.0167)	3.8278* (0.1816)				98.5496* (19.2122)	292.5355* (62.2073)
Veg. & Fruits (j = 3)	0.6640* (0.0101)			0.2647* (0.0338)	2.3827* (0.1738)	1.0085* (0.0016)	109.8036* (21.1633)	46.3374* (11.3889)
Grains (j = 4)	1.1683* (0.0046)			0.4583* (0.0573)	2.3368* (0.2371)	0.8163* (0.0226)	5.5481* (0.3613)	5.6008* (0.5040)
Others (j = 5)	0.0571 (0.9218)	0.1755 (0.3126)					5.11709D-08* (8.74930D-07)	3.98231D-11* (1.66715D-09)

Veg. is the abbreviation of vegetables.

* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.

The impact of individual nutrients in food group *j* on the respective food group prices is

$$x_{jh}^{\xi_{jjh}},\ j = 1,\ldots,5;\ h \in j. \tag{3.59}$$

For example, the impact of proteins on the price of the dairy (meats), estimated at the sample mean of the amount of protein contents in the dairy (meat) group, is 2.05 (3.83), which has a value that is greater than one. This result indicates that protein contents in the dairy (meats) group decrease the perceived price of the dairy (meat) products, thus increasing the demand for dairy (meat) products. On the other hand, the impact of vitamin I in the vegetables and fruit (grain) group, estimated at the sample means of the amount of vitamin I in the vegetables and fruit (grain) group, is 0.26 (0.46), which has a value of less than one. This suggests that the vitamin I contained in the vegetables and fruit (grain) products decreases the perceived price of vegetables and fruit (grain) products and will decrease the demand for vegetables and fruit (grains). The combined impact of all nutrients in the dairy (meat, vegetable and fruit, grains, and others) group can be estimated using formula (3.39), this estimate is shown in the last column of Table 3-6, that is, 15,781 (292, 46, 6, and $3.98\text{x}10^{-11}$ or zero). These results suggest that the nutritional contents decrease the perceived prices for meats, vegetables and fruits as a group, and grains, thus increasing the demand for them, while the nutritional contents increase the perceived price for the other group and then decrease the demand for fats and oils, sugar and sweets, and other miscellaneous. These findings are consistent with the rational behavior of consumers. In other words, the findings reflect that nutritional contents are dominant factors over prices as consumers or households demand their food.

CHAPTER 4
THE HOUSEHOLD PRODUCTION MODEL

The second approach considered in this study is based upon the household production theory (Becker, 1965; Mincer, 1962; Lancaster, 1966; Michael and Becker, 1973; Stigler and Becker, 1977). A household is assumed to produce utility-yielding, non-market consumable meals that contain nutrients, using market foods, time, and human capital as factor inputs. The salient feature of this approach is that it allows the researchers to calculate the nutrient (shadow) price and expenditure elasticities. In this model, the theoretical constraints -- such as adding-up, homogeneity, and symmetry -- are preserved.

This chapter consists of three sections. In the first section, the household production model is specified, and statistic data summary is reported in the following section. In the final third section, the estimation results are provided and summarized.

The Derivation of the Household Production Model

The household production theory is an integration of the consumer theory with the theory of the firm. Advantages attributed to the household production approach include the following: emphasis on the household as the decision-making unit; explicit consideration of the role of time in consumption decisions; and the ability of the theory to explain changes in consumption behavior on the basis of changes in household production relations and their implicit (shadow) prices, rather than relying on changes in "tastes" as in models based on traditional consumer theory such as the extended levels version of the Rotterdam model. The household production approach has been widely applied to different economic and social

issues -- such as those of intra-family bargaining power (Manser and Brown, 1980; McElroy and Horney, 1981; Carlin, 1991); travel time (Gronau, 1970); educational attainment; child care (Hill and Stafford, 1985; Stafford, 1987; Datcher-Loury, 1988); illegal activities; and the sexual division of labor (Juster, 1985; Hill and Juster, 1985).

In the household production model, two related optimization problems are considered. First, the household is assumed to minimize the expenditures necessary to achieve given levels of various nutrients and food consumed. Differentiating this expenditure or cost function then allows the calculation of shadow prices of nutrients in food intake. A representation of the household's optimization problem, which depends implicitly on these calculated shadow prices, is then formulated. Solution to this problem gives a system of equations that links the demand for nutrients to the nutrient shadow prices, food expenditure, and other related variables, such as household composition.

Theoretical Background

Assume that the vector $\mathbf{z} = [z_1, \ldots, z_{g-1}]$ represents g+1 factors consisting of the levels of g nutrients (z_h, $h \le g$) and the number of meals consumed (z_{g+1}). In fact, $z_h = \sum_j x_{jh}$, $h \le g$, $j = 1, \ldots, n_F$, n_F is the number of food items in the food group. Recall that x_{jh} is nutrient h embodied in food item j from the extended levels version of the Rotterdam model presented in chapter 3. According to the household production theory, it may be argued that, in order to produce the non-market vector $\mathbf{z}$, the household purchases a vector of food inputs (q_i, $i = 1, \ldots, n_F$; n_F food items) and labor inputs (l_j, $j = 1, \ldots, r$; r types of labor inputs) at the given market prices (p_i, $i = 1, \ldots, n_F$), wage rates (s_j, $j = 1, \ldots, r$), and capital stock,

k. In the following discussion, $\mathbf{q} = [q_1, \ldots, q_{n_F}; l_1, \ldots, l_r]$ and $\mathbf{p} = [p_1, \ldots, p_{n_F}; s_1, \ldots, s_r]$ are the column vectors of inputs and prices, respectively.

At the first stage the household may be characterized by cost-minimizing behavior with food inputs assumed to be weakly separable from all other commodity groups (Deaton and Muellbauer, 1980); this allows the expenditure allocation among food groups to be isolated from other commodities. The household's consumption choices then may be written as

$$\begin{aligned} &\min\ C = p'q \\ &\text{s.t.}\ \ H(q,z;k) \geq 0, \end{aligned} \tag{4.1}$$

where H(**q**, **z**; **k**) denotes the corresponding transformation function that converts food inputs (q_is), labor inputs (l_js), and fixed capital stocks (k, capital stocks are considered fixed in the short run) into the non-market output vector **z**. The solution to equation (4.1) is the household cost or expenditure function, $C^0 = x(\mathbf{p}, \mathbf{z}; \mathbf{k})$, indicating the minimal short-run cost of obtaining given levels of g nutrients and the number of meals at given prices and wages. The properties of this cost function are similar to those for the consumer cost function of traditional consumer theory. It is positively linear homogeneous, nondecreasing and concave in **p**, increasing in z and nonincreasing in **k**.

The shadow values of z_h are defined as (Deaton and Muellbauer, 1980):

$$\tau_h = \partial C / \partial z_h, \quad h = 1, \ldots, g+1. \tag{4.2}$$

The prominent advantage of utilizing the cost function to characterize the household's transformation of market inputs into nonmarket outputs is that it can provide a direct means of imputing values to the non-market vector **z**. Therefore, given the estimated cost function

(4.1), shadow prices for various nutrients and the number of meals consumed may be obtained by simply differentiating.

Given the shadow prices, the second-stage optimization problem of determining the demand levels of various nutrients and the number of meals can be defined:

$$\begin{aligned} &\max\ u(\mathbf{z},\mathbf{hc}) \\ &\text{s.t.}\quad C^0 = x(\mathbf{p},\mathbf{z};\mathbf{k}), \end{aligned} \tag{4.3}$$

or

$$\begin{aligned} &\max\ u(\mathbf{z},\mathbf{hc}) \\ &\text{s.t.}\quad C^0 = g(\tau'\mathbf{z}), \end{aligned} \tag{4.4}$$

where u represents a well-defined utility function; **hc** is a vector of household composition variables; $\tau = [\tau_1,\ldots,\tau_{g-1}]$ is a vector of the shadow prices; and C^0 is the minimized cost of equation (4.1) for given **p**. Note that this optimization problem is different from the conventional budget-constrained utility maximization problem of demand theory in the sense that the expenditure constraint in this context is a nonlinear function of $\tau'\mathbf{z}$. This nonlinearity of the expenditure of equation (4.4) is associated with the structure of the household's technology. In fact, the linear expenditure constraint corresponds to the assumption of constant return to scale (Deaton and Muellbauer, 1980). In more general cases concerning household technology, the nonlinear budget constraint $g(\tau'\mathbf{z})$ is thus more appropriate.

With the nonlinearity of the budget constraint, the explicit solution to this optimization problem is difficult to obtain. Nevertheless, given the shadow prices of **z**, the implicit form of solution to the second-stage optimization can be written as:

$$z_h = z_h(C^0,\tau,\mathbf{hc}),\qquad h = 1,\ldots,g+1, \tag{4.5}$$

which states that the demand for various nutrients and the number of meals is a function of

food expenditures C^0, which is determined by the first-stage optimization, shadow prices of $\mathbf{z}$, τ, and household composition, $\mathbf{hc}$. Therefore, given estimated shadow values τ_hs and expenditure, the price and expenditure elasticities for the non-market output z_hs and the impact of individual household members on the demand for nutrients can be obtained by estimating the demand system expressed in equation (4.5).

The Lancaster's linear characteristic model used in Pitt (1983) and Huang's (1996) studies is

$$\begin{aligned} &\max\ u(\mathbf{z},\mathbf{hc}) \\ &\text{s.t.}\ \ \mathbf{p}'\mathbf{q} = m \\ &\qquad\ \mathbf{z} = \mathbf{A}\mathbf{q}, \end{aligned} \tag{4.6}$$

where A is the transformation matrix of elements a_{jh} shown in equations (2.12) and (2.13) in chapter 2. The budget constraint can be rewritten as

$$p'(A^{-1})z = \underline{\tau}'\underline{z} = m, \tag{4.7}$$

where $\mathbf{p}'(A^{-1})$ or τ' can be considered as shadow prices of $\mathbf{z}$, and the solution of the maximization problem is

$$\mathbf{z} = \mathbf{z}(\tau, m, \mathbf{hc}), \tag{4.8}$$

which is similar to equation (4.5). This linear characteristic model is a special case of the lower-stage maximization problem of the household production model using a linear homogenous production function and same dimensions of $\mathbf{z}$ and $\mathbf{q}$. The model represented by equation (2.8) in Chapter 2 is a special case of the linear characteristic model when all shadow prices are deleted.

The hedonic price model is another special case of the lower-stage maximization problem of the household production model. The first-order condition of the maximization problem,

$$\begin{aligned}&\max\ u(\mathbf{z})\\&\text{s.t.}\ \ \mathbf{p}'\mathbf{q}=m,\end{aligned} \tag{4.9}$$

is

$$\sum_h (\partial u/\partial z_h)a_{ih}=\lambda p_i. \tag{4.10}$$

Since $1/\lambda$ is the marginal cost of utility, the shadow price is given by $\tau_h = (\partial u / \partial z_h)/\lambda$ so that we have

$$p_i=\sum_h \tau_h a_{ih}. \tag{4.11}$$

This result is similar to equation (2.9) in Chapter 2.

Model Specification

Since both wage rates of meal preparers and labor inputs in meal preparation were not reported in the 1987-88 NFCS, the wage and labor variables are deleted from **p** and **z** in equations (4.1) through (4.5). Given no a priori knowledge about cost function C^0, a translog cost function is adopted. Formally, this cost function can be written as

$$\begin{aligned}\ln C=\alpha_0&+\sum_i^{n_F}\alpha_i\ln p_i+\sum_h^{g-1}\beta_h\ln z_h+1/2\sum_i^{n_F}\sum_j^{n_F}\alpha_{ij}\ln p_i\ln p_j\\&+1/2\sum_h^{g-1}\sum_k^{g-1}\beta_{hk}\ln z_h\ln z_k+1/2\sum_i^{n_F}\sum_h^{g-1}\theta_{ih}\ln p_i\ln z_h.\end{aligned} \tag{4.12}$$

The number of parameters that need to be estimated can be reduced by imposing theoretically derived restrictions, such as linear homogeneity in prices and wages ($\sum_i \alpha_i = 1$, $i = 1, \ldots, n_F$; $\sum_j \alpha_{ij} = 0$, $\forall\, i, j = 1, \ldots, n_F$; and $\sum_h \theta_{ih} = 0$, $\forall\, h, h = 1, \ldots, g+1$) and symmetry of the cross-price, cross-wage, and cross-nutrient derivatives ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{hk} = \beta_{kh}$ (Young's theorem)).

Differentiating equation (4.12) with respect to each of the input prices and applying Shephard's lemma, factor budget share equations can be derived:

$$\frac{\partial \ln C}{\partial \ln p_i} = w_i^* = \alpha_i + \sum_j^{n_F} \alpha_{ij} \ln p_j + (1/2) \sum_h^{g+1} \theta_{ih} \ln z_h, \quad i = 1, \ldots, n_F, \tag{4.13}$$

where $w_i^* = p_i q_i / C$, is the average conditional propensity of total at-home food expenditure that may be spent spend on input group *i*, given the assumption of weak separability. Given equation (4.13), it is now easier to derive the adding-up conditions. That is, the sum of the left-hand side (LHS) of equation (4.13), or $\sum_i w_i^*$, is known to be one, and the sum of the RHS, or $\sum_i \alpha_i$, must be equal to the sum of the LHS, one, if $\sum_j \alpha_{ij} = 0$, $\alpha_{ij} = \alpha_{ji}$, and $\sum_h \theta_{ih} = 0$, $\forall$ i, j = 1, . . ., n_F; and $\forall$ *h*, *h* = 1, . . ., g+1. This demonstrates that equations (4.12) and (4.13) together are governed by the adding-up condition -- the highlight of an allocation model. The parameters α_{ij}s, θ_{ih}s show the effect of changes in **p** and **z** on factor budget shares. If θ_{ih} equals zero $\forall$ *i*, *h*, the household production technology is homothetic, meaning that factor shares are not affected by the levels of various nutrients and the number of meals at constant input prices.

The elasticity of substitution measures the curvature of an isoquant. More specifically, the elasticity of substitution measures the percentage change in the factor ratio divided by the percentage change in the technical rate of substitution, with output being fixed. The technical rate of substitution measures the slope of an isoquant. On the other hand, the elasticity of factor demand, or Hicksian price elasticity, measures the percentage change in the use of one factor for a percentage change in another factor price given that the output level is unchanged. The elasticities of substitution (Uzawa, 1962) and Hicksian own-price and cross-price elasticities of demand (Binswanger, 1974) are easily obtained given the share equation (4.13). The elasticities of substitution are

$$\sigma_{ii} = (\alpha_{ii} + w_i(w_i - 1))/w_i^2 \quad \text{and}$$
$$\sigma_{ij} = (\alpha_{ij}/w_i w_j) + 1 . \tag{4.14}$$

Note that, if $\alpha_{ij} = 0,\ \forall\, i, j$, the elasticity of substitution equals one. The Hicksian own-price and cross-price elasticities of demand are

$$\epsilon_{ii} = \sigma_{ii} w_i \quad \text{and}$$
$$\epsilon_{ij} = \sigma_{ij} w_j . \tag{4.15}$$

In addition, the shadow prices of the elements of **z** can be calculated by recognizing that

$$\tau_h = \frac{\partial C}{\partial z_h} = \frac{\partial \ln C}{\partial \ln z_h}\left(\frac{C}{z_h}\right) = \left(\beta_h + \sum_k^{g-1} \beta_{hk} \ln z_k + 1/2 \sum_i^{n_F} \theta_{ih} \ln p_i\right)\left(\frac{C}{z_h}\right),$$
$$h = 1, \ldots, g+1 . \tag{4.16}$$

Given the estimates of τ_hs from equation (4.16), the demand equations in equation (4.5) can be estimated. The approach first requires estimating shadow prices, based on equation (4.12). Generally speaking, the levels version of the Rotterdam model can be used to estimate the nutrient demand system shown in equation (4.5). Again, there are zero observations of household composition variables; therefore, the following demand relationship is used in the study:

$$z_h = \psi_0 + \sum_k \psi_{hk} \tau_k + \psi_{h1} C + \psi_{h2} C^2 + c_{h1} Ag_1 + c_{h2} Ag_2 + c_{h3} Ag_3$$
$$+ c_{h4} Ag_4 + c_{h5} Ag_5 + c_{h6} Ag_6 + d_h HZ^2, \quad h, k = 1, \ldots, g+1, \tag{4.17}$$

where C is the at-home food expenditure variable; Ag_1, Ag_2, Ag_3, Ag_4, Ag_5, and Ag_6 represent the number of household members aged from zero to six, seven to 12, 13 to 18, 19 to 45, 46 to 60, and over 60, respectively; and HZ denotes the variable of household size, which is the sum of Ag_1 through Ag_6. Note that household composition variables, $Ag_1, \ldots, Ag_6$, and HZ^2, compose **hc** above. This formulation explains that the amount of nutrients consumed is not only a function of the shadow prices of nutrients and food expenditure but

is the set of household composition variables as well. Note that since all τ_hs are themselves functions of z_h, the estimation of (4.17), with no consideration given to the correlation between τ_hs and z_hs, will result in bias. Therefore, a two-stage estimation, calculated using an instrumental variables estimator, provides consistent estimates of τ_hs in equation (4.16), these estimates are then used in the estimation of (4.17) (Mendelsohn, 1984).

According to the demand theory, the own (shadow) price parameters ψ_{hh}s are expected to be negative (downward-sloping demand), and the expenditure parameters ψ_{h1}s are expected to be positive if all nutrients are normal goods. In addition, the demand for each nutrient is assumed to be concave in expenditure (which means that the demand function (4.17) is increasing at a decreasing rate as expenditure increases); the expenditure squared parameters ψ_{h2}s are thus expected to be negative. In addition to the ability of calculating the price and expenditure elasticities of nutrients, (4.17) also allows us to explore the effects of household composition variables on nutrient demand.

Data

The same data set used in the extended levels version of Rotterdam model is also used to estimate the household production model. The sample consists of a total of 4,155 observations, or households. Summary statistics of the data for variables pertaining to models (4.12) and (4.13) are shown in Table 4-1. An average household with 2.81 persons consumed 72.84 pounds of food in 48.37 meals and spent \$62.03 on food per week. The average consumption of dairy products, meats and other protein source products, vegetables and fruit, grains, and all other foods are 20.64, 13.12, 24.24, 5.17, and 9.67 pounds per week per household, respectively; their respective expenditures are \$7.63, \$21.40, \$12.62, \$10.19, and

Table 4-1. The Means and Standard Errors of Variables.

Variables	Mean	Standard Deviation
Total Food Quantity (pounds)	72.84	44.92
Total Food Consumption Value (dollars)	62.03	37.10
Carbohydrates (grams)	5,234	3,645
Fats and Oils (grams)	2,186	1,559
Proteins (grams)	1,689	1,079
Vitamin I (milligrams)	3,136	2,186
Vitamin II (micrograms)	5,694	3,864
Fibers (grams)	313	215
Minerals (milligrams)	165,686	103,230
Number of Meal Equivalent	48.37	26.00
Household Size	2.81	1.44
Quantity of Dairy (pounds)	20.64	17.65
Quantity of Meats (pounds)	13.12	10.00
Quantity of Vegetables and Fruit (pounds)	24.24	17.38
Quantity of Grains (pounds)	5.17	4.26
Quantity of Others (pounds)	9.67	11.02
Value of Dairy (dollars)	7.63	6.18
Value of Meats (dollars)	21.40	16.12
Value of Vegetables and Fruit (dollars)	12.62	8.75
Value of Grains (dollars)	10.19	8.11
Value of Others (dollars)	10.18	9.68
Budget Share of Dairy	0.125	0.069
Budget Share of Meats	0.339	0.128
Budget Share of Vegetables and Fruit	0.212	0.095
Budget Share of Grains	0.165	0.084
Budget Share of Others	0.159	0.090

Source: USDA/ARS (1994).

\$10.18. The budget shares of these food groups are 0.125, 0.339, 0.212, 0.165, and 0.159, respectively. The average household consumption of carbohydrates, fats and oils, proteins, vitamins I, vitamins II, fibers, and minerals are 5,234 grams, 2,186 grams, 1,689 grams, 3,136 milligrams, 5,694 micrograms, 313 grams, and 165,686 milligrams, respectively. There is an approximate 52-pound discrepancy between the total weight of nutrients (about 21 lbs) and the total weight of food items (about 73 lbs). The plausible explanation is that all food items contain various portions of water.

Results

In the household production model ((4.12) and (4.13) together), the food expenditure variable C is measured in dollars; p_is are input market prices in dollars with $i = 1$ for dairy group, $i = 2$ for meat group, $i = 3$ for vegetables and fruit group, $i = 4$ for grain group, and $i = 5$ ($= n_F$) for the other group; z_hs are the quantities of outputs, or nutrients, with z_1 for carbohydrates, z_2 for fats and oils, z_3 for proteins, z_4 for vitamin group I, z_5 for vitamin group II, z_6 for digestible fibers, z_7 (z_g) for minerals, and z_8 (z_{g+1}) for total food quantity. Note that the nutrient variables, z_h, $h = 1, \ldots, 7$, are the aggregates across five food groups; they are different from those used in the levels version of the Rotterdam model. z_hs are defined in their own units: carbohydrates, fats and oils, proteins, and digestible fibers are in grams; vitamin group I and minerals are in milligrams; and vitamin group II is in micrograms.

To correct for the effects of the household composition on food consumption, the total quantity of food consumption, z_{g+1} (z_8), is defined as the number of meals equivalent. This number includes (1) meals reported as eaten at home by members (adjusted proportionately with meals eaten away from home to total 21 meals in a week to account for

skipped meals and for snacks that might substitute for or supplement meals); (2) meals eaten by guests, boarders, roomers, and employees; and (3) meal equivalents of refreshment served to guests (that is, one or two foods equal one-fourth meal; more than two foods equal one-half meal).

Given that the disturbance terms in models (4.12) and (4.13) together are seemingly unrelated across equations; and that this model is an allocation model with theoretical constraints, such as symmetry and homogeneity, the translog cost function (4.12) in conjunction with (n_F - 1), or four share equations (4.13), is estimated using the iterated seemingly unrelated regression or the IZEF procedure as in the case of the extended levels version of the Rotterdam model.

The translog cost function (4.12) with five food groups, seven nutrients, and the total number of meals eaten at home has 91 parameters after imposing the homogeneity and the symmetry conditions. Results are shown in Table 4-2. The translog specification appears to fit the data quite successfully, with 59 of the 91 estimated parameters (or 65 percent) exceeding twice their associated standard errors.

The estimated parameters of particular interest are θ_{ih}s. Parameters θ_{ih} for $h \leq 7$ indicates the effect of changes in the hth nutrient contained in individual food groups on the ith budget share, and θ_{i8} indicates the effect of changes in the number of meals equivalent on the ith food group budget share. As shown in Table 4-2, the nutrient parameter estimates, θ_{ih}s, $h \leq 7$, have both positive and negative signs, indicating both substitution ($\theta_{ih} < 0$) and complementary ($\theta_{ih} > 0$) relationships, and 36 out of 40 are significantly different from zero at $\alpha = 0.05$ level. For example, the estimates indicate that budget shares of grains and other groups increase as carbohydrate content in the final goods, non-market outputs, or nutritional

Table 4-2. The Translog Cost Function Parameter Estimates.

Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error	Parameter	Estimate	Standard Error
α_0	-8.56218*	1.35799	β_{17}	-0.03281	0.04246	θ_{16}	-0.12929*	0.00566
α_1	-0.97226*	0.03185	β_{18}	-0.04308*	0.01779	θ_{17}	0.44770*	0.01260
α_2	1.65562*	0.03883	β_{22}	0.09595*	0.02058	θ_{18}	0.01778*	0.00472
α_3	0.34374*	0.03274	β_{23}	-0.09282*	0.02872	θ_{21}	-0.20692*	0.00883
α_4	0.04409	0.03022	β_{24}	0.01386	0.01566	θ_{22}	0.11935*	0.00769
α_5^{a}	-0.07118	0.04255	β_{25}	-0.03365	0.01956	θ_{23}	0.72837*	0.01176
β_1	0.18533	0.21502	β_{26}	0.00282	0.01643	θ_{24}	-0.02050*	0.00638
β_2	-0.29191	0.18274	β_{27}	0.07956*	0.03556	θ_{25}	-0.01356	0.00814
β_3	0.29551	0.32224	β_{28}	0.02231	0.01490	θ_{26}	-0.03692*	0.00692
β_4	0.05554	0.16025	β_{33}	0.27374*	0.06140	θ_{27}	-0.57170*	0.01530
β_5	-0.20138	0.20161	β_{34}	-0.07272*	0.02486	θ_{28}	-0.00625	0.00554
β_6	-0.40245*	0.17766	β_{35}	0.01524	0.03000	θ_{31}	-0.08181*	0.00745
β_7	1.50927*	0.48634	β_{36}	-0.04993	0.02598	θ_{32}	-0.06141*	0.00651
β_8	0.03859	0.15180	β_{37}	-0.08527	0.06443	θ_{33}	-0.26349*	0.01002
α_{11}	0.05437*	0.00200	β_{38}	-0.07885*	0.02339	θ_{34}	0.23133*	0.00542
α_{12}	-0.02640*	0.00194	β_{44}	0.01090	0.01809	θ_{35}	-0.07142*	0.00686
α_{13}	-0.00835*	0.00164	β_{45}	0.04227*	0.01738	θ_{36}	0.14713*	0.00585
α_{14}	-0.01637*	0.00131	β_{46}	0.01158	0.01354	θ_{37}	0.08554*	0.01290
α_{15}^{a}	-0.00325*	0.00131	β_{47}	0.02560	0.03142	θ_{38}	-0.01085*	0.00461
α_{22}	0.14666*	0.00300	β_{48}	-0.00031	0.01258	θ_{41}	0.22936*	0.00692
α_{23}	-0.06195*	0.00205	β_{55}	-0.07943*	0.02515	θ_{42}	-0.05241*	0.00605
α_{24}	-0.04808*	0.00164	β_{56}	-0.00101	0.01723	θ_{43}	-0.12572*	0.00927
α_{25}^{a}	-0.01024*	0.00163	β_{57}	0.06309	0.03870	θ_{44}	-0.12184*	0.00498
α_{33}	0.09837*	0.00256	β_{58}	0.00565	0.01647	θ_{45}	0.06141*	0.00640
α_{34}	-0.02580*	0.00152	β_{66}	-0.08030*	0.01706	θ_{46}	0.03527*	0.00545
α_{35}^{a}	-0.00228	0.00147	β_{67}	0.04541	0.03214	θ_{47}	-0.02426*	0.01187
α_{44}	0.09515*	0.00167	β_{68}	-0.00222	0.01321	θ_{48}	0.00366	0.00443
α_{45}^{a}	-0.00490*	0.00121	β_{77}	-0.16230	0.09562	θ_{51}^{a}	0.08918*	0.00973
α_{55}^{a}	0.02067*	0.00198	β_{78}	0.03994	0.02918	θ_{52}^{a}	0.09081*	0.00857
β_{11}	0.02799	0.03286	β_{88}	0.06503*	0.01607	θ_{53}^{a}	-0.18331*	0.01294
β_{12}	-0.07341*	0.02044	θ_{11}	-0.02981*	0.00723	θ_{54}^{a}	-0.02405*	0.00713
β_{13}	0.08773*	0.03161	θ_{12}	-0.09635*	0.00633	θ_{55}^{a}	-0.01086	0.00900
β_{14}	-0.02546	0.01784	θ_{13}	-0.15585*	0.00963	θ_{56}^{a}	-0.01620*	0.00758
β_{15}	-0.01501	0.02308	θ_{14}	-0.06494*	0.00522	θ_{57}^{a}	0.06273*	0.01680
β_{16}	0.07255*	0.02098	θ_{15}	0.03443*	0.00666	θ_{58}^{a}	-0.00434*	0.00015

* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.

[a] Denotes that the estimate is derived from the linear homogeneity condition

contents in home-prepared meals increases, while budget shares of dairy, meats, and vegetables and fruit as a group decrease (θ_{11} = -0.030, θ_{21} = -0.207, θ_{31} = -0.082, θ_{41} = 0.229; θ_{51} = 0.089). Budget shares of dairy, vegetables and fruit as a group, and grains decrease as the fat content in the non-market outputs increases, while the budget shares of meats and the others groups increase (θ_{12} = -0.096, θ_{22} = 0.119, θ_{32} = -0.061, θ_{42} = -0.052, θ_{52} = 0.091); and budget shares of vegetables and fruit as a group and grains increase as the fiber content in the non-market outputs increases, while the budget shares of dairy, meats and the others groups decrease, *ceteris paribus* (θ_{16} = -0.129, θ_{26} = -0.037, θ_{36} = 0.147, θ_{46} = 0.035, θ_{56} = - 0.016). These findings are consistent with the nutritional nature of the five food groups considered. θ_{i8}s have both positive and negative signs. The estimated θ_{i8} for the dairy group is positive (θ_{18} = 0.018), while those for the vegetables and fruit, and other groups are negative (θ_{38} = -0.011, and θ_{58} = -0.004). This result reflects the fact that budget share for dairy increases as the number of meals consumed by the household increases, while, assuming constant food prices, the budget shares of vegetables and fruit and the others food groups decrease. These are reasonable outcomes given that there is a budget constraint and that the adding-up condition needs to be met.

Both elasticities of substitution and elasticities of factor demand, evaluated at the means of the budget shares, are reported in Table 4-3. Equation (4.14) is used to report he elasticity estimates of substitution in Table 4-3. All cross-elasticities of substitution are positive, which reveals that all food groups are complements to each other, and own-elasticities of substitution are negative. These are expected results given the definition of the elasticity of substitution.

Table 4-3. Elasticities of Substitution and Factor Price Elasticities Calculated at Means of Data.

Food Groups	Dairy	Meats	Veg & Fruit	Grains	Others
			Elasticity of Substitution		
Dairy	-3.52396* (0.12868)	0.37500* (0.04589)	0.68440* (0.06213)	0.20153* (0.06411)	0.83612* (0.06596)
Meats		-0.67358* (0.02611)	0.13991* (0.02848)	0.13825* (0.02945)	0.81063* (0.03016)
Veg. & Fruit			-1.52752* (0.05669)	0.26179* (0.04345)	0.93271* (0.04351)
Grains				-1.56316* (0.06169)	0.81306* (0.04613)
Others					-4.45966* (0.07772)
			Factor Price Elasticity		
Dairy	-0.43897* (0.01603)	0.12715* (0.01556)	0.14537* (0.01320)	0.03316* (0.01055)	0.13329* (0.01052)
Meats	0.04671* (0.00572)	-0.22840* (0.00885)	0.02972* (0.00605)	0.02275* (0.00485)	0.12922* (0.00481)
Veg. & Fruit	0.08525* (0.00774)	0.04744* (0.00966)	-0.32445* (0.01204)	0.04307* (0.00715)	0.14868* (0.00694)
Grains	0.02510* (0.00799)	0.04688* (0.00999)	0.05561* (0.00923)	-0.25720* (0.01015)	0.12961* (0.00735)
Others	0.10415* (0.00822)	0.27487* (0.01023)	0.19811* (0.00924)	0.13378* (0.00759)	-0.71091* (0.01239)

* Denotes that the estimate is significantly different from zero at $\alpha = 0.05$ level.
The values in parentheses are the corresponding standard errors.
Veg. is the abbreviation for vegetables.

Elasticity of factor demand or the Hicksian (compensated) price elasticity, equation (4.15), captures the effect of a factor price change in terms of the percentage change in the usage of own or other factors in production. In Table 4-3, all own-price elasticities of factor demand have the correct negative sign as expected; are significantly different from zero at $\alpha = 0.05$ level; and are inelastic; that is, the demand of a food group in question will decrease less proportionately as its price increases. All the cross-price elasticity estimates are positive; significantly different from zero at $\alpha = 0.05$ level and inelastic, indicating there is a substitution relationship for any pair of food groups considered. In addition, an increase in one food price will lead to an increase in the use of any other food less proportionately.

Shadow prices for nutrients in the consumption of five major food groups can be calculated from (4.16) given the estimates of β_h, β_{hk}, and θ_{ih}. Table 4-4 shows the mean shadow prices of the nutrient variables, z_hs, $i \leq 7$, and of the meals variable, z_8. The shadow prices ranged from 0.02274 for proteins to -0.00019 for vitamin II. The shadow price for proteins is considered significantly different from zero at $\alpha = 0.05$ level; the shadow price for vitamins C, B-6, thiamin, riboflavin, and niacin as a group or vitamin I is significantly different from zero at $\alpha = 0.10$ level; while the shadow price for fats and oils is significantly different from zero at $\alpha = 0.20$ level, implying that the household does value the factor of those certain vitamins mentioned above, proteins, and fats and oils in its food consumption. The variation in shadow prices suggests that different nutrients cost different prices to consumers. In general, consumers place the highest value on proteins and the lowest value on minerals. The negative value for vitamin group II may imply that the general public does not recognize the importance of folate and Vitamin B-12. Consequently, the sign for the own-price elasticity of vitamin group II is positive (see Table 4-3).

Table 4-4. Mean Shadow Prices of Nutrients.

Nutrients	Mean	Standard Deviation
Carbohydrates	0.00147	0.00129
Fats and oils	0.00268	0.00199
Proteins	0.02274	0.00981
Vitamin I	0.00308	0.00175
Vitamin II	-0.00019	0.00044
Fibers	0.01626	0.01937
Minerals	0.00002	0.00006
Number of meal equivalent	0.00899	0.06250

Recall that equation (4.17) is the nutrient demand function in the second stage of the household production model. Using the least squares method (LS), the parameter estimates of demand equation (4.17) are reported in Table 4-5. Results show that most (shadow) price parameters, all expenditure parameters, and most household composition parameters are significantly different from zero at $\alpha = 0.05$ level. Own price parameter estimates for all nutrients have expected negative signs; an indication of this is that, as the prices of nutrients increase, consumers or households decrease their consumption of these nutrients. This result is consistent with the demand theory. Most cross-price parameters are negative, suggesting complementary relationships among nutrients. The expenditure parameter estimates of ψ_{h1} and ψ_{h2} have the correct signs; that is, the demand for each individual nutrient is shown to be concave (or increasing at decreasing rate) in expenditure. For the first seven demand equations of (4.17), the parameter estimates associated with household composition variables $Ag_1, \ldots, Ag_6$ are all negative and almost all of them are significantly different from zero at $\alpha = 0.05$ level. On the other hand, the finding is that all the estimated parameters of household composition variables in the demand equation of the number of meals are positive and statistically significant at the same α level. Since the demand functions (4.17) are not linear functions in Ag_gs, the impacts of $Ag_1, \ldots, Ag_6$ on the nutrient demand cannot simply be judged by looking at their associated parameter estimates. These impacts will be examined and discussed later.

The own- and cross-price, expenditure, and meal equivalent elasticities for nutrients ($h = 1, \ldots, 8$) are

$$\text{own-price elasticity: } \zeta_{hh} = \frac{\partial z_h}{\partial \pi_h}\frac{\pi_h}{z_h} = \psi_{hh}\frac{\pi_h}{z_h}, \quad h = 1, \ldots, 8; \tag{4.18}$$

Table 4-5. Estimation of Demand Equation (4.17).

Variable	Nutrients							# of (Equivalent)
	Carbohydrates (z_1)	Fats & Oils (z_2)	Proteins (z_3)	Vitamin I (z_4)	Vitamin II (z_5)	Fibers (z_6)	Minerals (z_7)	Meals (z_8)
Intercept	4.244e+03*	1.754e+03*	1.267e+03*	2.621e+03*	4.132e+03*	2.775e+02*	1.415e+05*	1.376e+01*
	(1.638e+02)	(7.107e+01)	(3.351e+01)	(1.141e+02)	(2.078e+02)	(1.156e+01)	(3.423e+03)	(7.990e-01)
Sp1	-4.680e+05*	-2.153e+05*	-6.746e+04*	-2.093e+05*	-7.091e+04*	-9.637e+03*	-1.005e+07*	-1.309e+03*
	(2.313e+04)	(1.004e+04)	(4.733e+03)	(1.611e+04)	(2.935e+04)	(1.633e+03)	(4.834e+05)	(1.128e+02)
Sp2	-2.263e+05*	-2.168e+04*	-3.198e+04*	-9.300e+03*	-2.647e+05*	-1.015e+04*	-2.684e+06*	3.649e+01
	(1.485e+04)	(6.445e+03)	(3.039e+03)	(1.034e+04)	(1.885e+04)	(1.049e+03)	(3.104e+05)	(7.246e+01)
Sp3	-6.102e+04*	-5.027e+04*	-3.694e+04*	-2.281e+04*	-4.494e+04*	-4.482e+03*	-3.498e+06*	-3.334e+02*
	(3.494e+03)	(1.516e+03)	(7.148e+02)	(2.433e+03)	(4.433e+03)	(2.466e+02)	(7.301e+04)	(1.704e+01)
Sp4	-2.370e+05*	-1.609e+04	-4.246e+03	-4.218e+05*	-5.055e+05*	-5.329e+03*	-1.038e+06	8.917e+01
	(1.913e+04)	(8.301e+03)	(3.914e+03)	(1.332e+04)	(2.427e+04)	(1.350e+03)	(3.998e+05)	(9.332e+01)
Sp5	-7.250e+05*	-1.864e+05*	1.546e+04	-2.114e+05*	-1.945e+06*	-3.679e+04*	7.761e+06*	2.339e+02
	(8.013e+04)	(3.477e+04)	(1.639e+04)	(5.580e+04)	(1.017e+05)	(5.656e+03)	(1.674e+06)	(3.909e+02)
Sp6	-1.061e+04*	-1.950e+03*	-3.231e+03*	-4.197e+03*	-1.268e+04*	-3.106e+03*	-4.195e+05*	-4.048e+01*
	(1.444e+03)	(6.266e+02)	(2.954e+02)	(1.006e+03)	(1.832e+03)	(1.019e+02)	(3.018e+04)	(7.044e+00)
Sp7	-6.942e+06*	-2.101e+06*	-3.032e+06*	-4.815e+05	-5.897e+06*	-5.173e+05*	-3.859e+08*	-2.273e+04*
	(5.339e+05)	(2.317e+05)	(1.092e+05)	(3.718e+05)	(6.774e+05)	(3.769e+04)	(1.116e+07)	(2.604e+03)
Sp8	-2.897e+03*	-1.290e+02	-1.473e+03*	8.335e+02*	4.176e+03*	-2.600e+01	1.773e+04	4.665e+01*
	(5.488e+02)	(2.381e+02)	(1.123e+02)	(3.822e+02)	(6.963e+02)	(3.874e+01)	(1.147e+04)	(2.677e+00)
C	8.327e+01*	3.906e+01*	2.767e+01*	5.402e+01*	8.638e+01*	4.920e+00*	2.846e+03*	1.551e-01*
	(1.930e+00)	(8.376e-01)	(3.949e-01)	(1.344e+00)	(2.449e+00)	(1.363e-01)	(4.034e+01)	(9.416e-03)
C^2	-7.349e-02*	-1.874e-02*	-1.954e-02*	-2.875e-02*	-6.182e-02*	-3.676e-03*	-2.355e+00*	-1.021e-04*
	(7.395e-03)	(2.209e-03)	(1.513e-03)	(5.150e-03)	(9.383e-03)	(5.220e-04)	(1.545e-01)	(3.607e-05)
Ag1	-3.381e+02*	-2.580e+02*	-1.167e+02*	-3.831e+02*	-3.384e+02*	-3.843e+01*	-1.605e+04*	1.353e+01*
	(8.379e+01)	(3.636e+01)	(1.714e+01)	(5.835e+01)	(1.063e+02)	(5.915e+00)	(1.751e+03)	(4.087e-01)
Ag2	-2.344e+02*	-1.777e+02*	-9.737e+01*	-2.929e+02*	-1.873e+02	-3.778e+01*	-1.274e+04*	1.045e+01*
	(8.957e+01)	(3.887e+01)	(1.833e+01)	(6.238e+01)	(1.136e+02)	(6.323e+00)	(1.872e+03)	(4.369e-01)
Ag3	-1.720e+02	-1.693e+02*	-8.096e+01*	-2.321e+02*	-9.848e+01	-3.731e+01*	-1.167e+04*	9.095e+00*
	(8.776e+01)	(3.808e+01)	(1.796e+01)	(6.111e+01)	(1.113e+02)	(6.195e+00)	(1.834e+03)	(4.281e-01)

Table 4-5. Continued.

Variable	Nutrient							# of (Equivalent) Meals
	Carbohydrates (z_1)	Fats & Oils (z_2)	Proteins (z_3)	Vitamin I (z_4)	Vitamin II (z_5)	Fibers (z_6)	Minerals (z_7)	
Ag4	-5.962e+02*	-1.804e+02*	-1.130e+02*	-3.779e+02*	-5.662e+02*	-4.575e+01*	-1.992e+04*	9.741e+00*
	(7.369e+01)	(3.197e+01)	(1.508e+01)	(5.132e+01)	(9.349e+01)	(5.202e+00)	(1.540e+03)	(3.594e-01)
Ag5	-5.940e+02*	-2 425e+02*	-9.643e+01*	-2.721e+02*	-3.420e+02*	-3.358e+01*	-1.859e+04*	1.111e+01*
	(8.104e+01)	(3.517e+01)	(1 658e+01)	(5.644e+01)	(1.028e+02)	(5.721e+00)	(1.694e+03)	(3 953e-01)
Ag6	-5.913e+02*	-2.895e+02*	-1.205e+02*	-3.105e+02*	-3.773e+02*	-3.420e+01*	-2.076e+04*	1.224e+01*
	(9.139e+01)	(3.966e+01)	(1.870e+01)	(6.365e+01)	(1.160e+02)	(6.452e+00)	(1.910e+03)	(4.458e-01)
HZ^2	1.170e+02*	3.023e+01*	2.647e+01*	4.195e+01*	9.240e+01*	7.348e+00*	2.919e+03*	5.311e-01*
	(8.862e+00)	(3.845e+00)	(1.813e+00)	(6.172e+00)	(1.124e+01)	(6.256e-01)	(1.852e+02)	(4.323e-02)

* Denotes that the parameter estimate is significantly from zero at $\alpha = 0.05$ level.
The values in parentheses are the corresponding standard deviations

$$\text{cross-price elasticity: } \zeta_{hk} = \frac{\partial z_h}{\partial \pi_k}\frac{\pi_k}{z_h} = \psi_{hk}\frac{\pi_k}{z_h}, \quad h,k = 1,\ldots,8; \tag{4.19}$$

and

$$\text{expenditure elasticity: } \zeta_{hc} = \frac{\partial z_h}{\partial C}\frac{C}{z_h} = (\psi_{h1} + 2\psi_{h2}C)\frac{C}{z_h}, \quad h = 1,\ldots,8. \tag{4.20}$$

These own- and cross- price elasticities and expenditure elasticities are calculated at sample means and reported in Table 4-6. Results in Table 4-6 show that the (shadow) own-price elasticity estimates are negative except those for vitamin II and the number of at-home meals; all cross-price elasticity estimates are negative, inelastic, and small in magnitude; expenditure elasticity estimates of carbohydrates, proteins, vitamin II, fibers, minerals, and the number of at-home meals are inelastic (ζ_{1c} = 0.88; ζ_{3c} = 0.93; ζ_{5c} = 0.86; ζ_{6c} = 0.90; ζ_{7c} = 0.96; ζ_{8c} = 0.18) and the expenditure elasticity estimates for fats and oils and vitamin I are unitarily elastic (ζ_{2c} = 1.04; ζ_{4c} = 1.00). The small and inelastic own-price-nutrient elasticity estimates indicate that consumers will strive for nutrients with little regard to the costs associated with them. The expenditure elasticity estimates suggest that consumers will demand relatively more fats and oils and vitamin I as compared to carbohydrates, protein, vitamin II, fiber, minerals, and the number of home-prepared meals as their incomes increase.

The impacts of the addition of a type g household member, Ag_g, can be evaluated as

$$\frac{\partial z_h}{\partial Ag_g} = c_{hg} + 2d_h HZ, \quad h = 1,\ldots,8; \ g = 1,\ldots,6. \tag{4.21}$$

These impacts calculated at sample means of HZ are reported in Table 4-7.

Table 4-6. Price and Expenditure Elasticities Calculated at Sample Means.

Nutrients	Price								Expenditure
	Carbohydrates	Fats and Oils	Proteins	Vitamin I	Vitamin II	Fibers	Minerals	# of (Equivalent) Meal	
Carbohydrates	-0.13131* (0.00649)	-0.11600* (0.00761)	-0.26509* (0.01518)	-0.13931* (0.01124)	0.02646* (0.00292)	-0.03295* (0.00448)	-0.02135* (0.00164)	-0.00497* (0.00094)	0.87877* (0.01526)
Fats and Oils	-0.14463* (0.00674)	-0.02661* (0.00791)	-0.52307* (0.01577)	-0.02265 (0.01168)	0.01629* (0.00304)	-0.01450* (0.00466)	-0.01547* (0.00171)	0.00053 (0.00098)	1.04249* (0.01586)
Proteins	-0.05865* (0.00411)	-0.05079* (0.00483)	-0.49735* (0.00962)	-0.00773 (0.00713)	-0.00175 (0.00185)	-0.03109* (0.00284)	-0.02891* (0.00104)	-0.00784* (0.00060)	0.92694* (0.00967)
Vitamin I	-0.09801* (0.00754)	-0.00795 (0.00885)	-0.16542* (0.01764)	-0.41375* (0.01307)	0.01288* (0.00340)	-0.02175* (0.00521)	-0.00247 (0.00191)	0.00239* (0.00110)	0.99783* (0.01773)
Vitamin II	-0.01829* (0.00757)	-0.12472* (0.00888)	-0.17948* (0.01770)	-0.27314* (0.01311)	0.06535* (0.00341)	-0.03619* (0.00523)	-0.01668* (0.00192)	0.00659* (0.00110)	0.85748* (0.01780)
Fibers	-0.04518* (0.00766)	-0.08695* (0.00898)	-0.32540* (0.01791)	-0.05234* (0.01326)	0.02244* (0.00345)	-0.16118* (0.00529)	-0.02659* (0.00194)	-0.00075 (0.00111)	0.88390* (0.01800)
Minerals	-0.08908* (0.00428)	-0.04346* (0.00503)	-0.48006* (0.01002)	-0.01927 (0.00742)	-0.00895* (0.00193)	-0.04116* (0.00296)	-0.03750* (0.00108)	0.00096 (0.00062)	0.95604* (0.01007)
# of (Equivalent) Meals	-0.03973* (0.00343)	0.00202 (0.00402)	-0.15675* (0.00801)	0.00567 (0.00594)	-0.00092 (0.00154)	-0.01361* (0.00237)	-0.00757* (0.00087)	0.00867* (0.00050)	0.18270* (0.00806)

* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.
The values in parentheses are the corresponding standard errors.

Table 4-7. The Impacts of Household Composition Variables on Nutrient Intakes.

Nutrients	Household Composition					
	Ag_1 (0-6)	Ag_2 (7-12)	Ag_3 (13-18)	Ag_4 (19-45)	Ag_5 (45-60)	Ag_6 (> 60)
Carbohydrates (grams)	318.73* (50.52)	422.49* (50.02)	484.91* (54.88)	60.66 (46.40)	62.83 (53.02)	65.61 (64.80)
Fats and Oils (grams)	-88.28* (21.92)	-7.95 (23.88)	0.46 (23.81)	-10.64 (20.14)	-72.78* (23.00)	-119.75* (28.12)
Proteins (grams)	31.98* (10.34)	51.29* (11.26)	67.70* (11.23)	35.61* (9.49)	52.23* (10.85)	28.12* (13 26)
Vitamin I (milligrams)	-147.45* (35.18)	-57.31 (38.32)	3.55 (38.22)	-142.26* (32.32)	-36.45 (36.92)	-74.87 (45.12)
Vitamin II (micrograms)	180.55* (64.10)	331.60* (69.63)	420.45* (69.81)	-47.27 (58.88)	176.92* (67.27)	141.65 (82.21)
Fibers (grams)	2.83 (3.57)	3.49 (3.88)	3.95 (3.87)	-4.49 (3.28)	7.68* (3.74)	7.07 (4.57)
Minerals (milligrams)	338.72 (1055.69)	3650.02* (1149.88)	4722.47* (1146.89)	-3526.21* (969.74)	-2198.08* (1108.04)	-4368.39* (1354.09)
# of (Equivalent) Meals (# of meals)	16.51* (0.25)	13.43* (0.27)	12.08* (0.27)	12.72* (0.23)	14.09* (0.26)	15.22* (0.32)

* Denotes that the parameter estimate is significantly different from zero at $\alpha = 0.05$ level.
The values parentheses are the corresponding standard errors.

For carbohydrates, on average, the weekly carbohydrate intakes per household increase by 319, 442, and 485 grams for an addition of household member in the age groups 1, 2, and 3 (Ag_1, Ag_2, and Ag_3), respectively. The average weekly fat and oil intakes per household decrease as their members increase for age groups 1, 5 (Ag_5), and 6 (Ag_6). Given the fact that the older population is relatively concerned about the cholesterol levels in their blood stream and is cautious about fats and oils intake, this outcome is expected. As the number of members increases, the marginal weekly protein intakes will increase for all age groups. This finding is consistent with the notion that food consumption as well as nutrient intakes increase as the number of members in a household increase. However, another finding that the weekly household consumption for vitamin I -- that is, vitamins C and B-6, thiamin, riboflavin, and niacin as a group decrease for an addition of a household member in groups 1, 4 (Ag_4), and 6 -- is surprising. The weekly household consumption for vitamin group II will increase when the numbers of members increase in all age groups except groups 4 and 6. Weekly fiber intakes are found to increase as the number of members increase in group 5, which is a reasonable outcome. Weekly mineral intakes are found to increase for groups 2 and 3; and to decrease for groups 4, 5, and 6 as members increase at margin. The interpretation might be that people between the ages of seven and 18 usually eat home-prepared meals that are more nutritious and balanced; while those aged from 19 years of age to over 60 tend to eat convenience foods while they are working during the day, thus consuming less balanced meals. Finally, for the number of meals equivalent, the weekly increase is 17, 13, 12, 13, 14, and 15 meals per household, respectively, for the six age groups considered in this study.

This household production model specification attempts to characterize the household's preference toward nutrients in food consumption. The household production model allows the calculation of the shadow prices (shown in Table 4-4) or in fact the marginal costs of obtaining an extra unit of individual nutrients. These shadow price estimates can be very helpful for policy makers in terms of designing food-related programs to promote public nutrition. For example, if the policy targets the promotion of nutritional quality in diet in terms of less fats and oils; and more fibers, vitamins, and minerals, then a policy instrument that can increase the shadow prices for fats and oils and decrease the shadow prices for fibers, vitamins, and minerals will be desired. Based on the estimation of demand function (4.17), own-price elasticities of demand for the seven nutrients considered have correct negative signs (except those for vitamin group II and the meals equivalent) and are inelastic; fats and oils and vitamin I have unit expenditure elasticities, while carbohydrates, proteins, vitamin II, fibers, and minerals are necessities. The positive price elasticity for vitamin group II is a result from its negative shadow price, while the positive price elasticity for the meals equivalent might stem in the inter-relationship between dining-out and home meals, which is beyond the scope of this study due to the lack of available data for dining out. Most cross-price elasticities of nutrients are negative, indicating complementarity. These outcomes appear to be reasonable results.

The household production approach allows us to incorporate nutrient factors into the food consumption decision by households. However, the cross effect between two nutrients from different food categories cannot be identified because nutrient variables are aggregated across all food groups in this study. This problem can be solved by modifying the household production model through a more elaborate definition of variables. However, such an

extension will lead to more complicated estimation. Nevertheless, a levels version of the Rotterdam model can serve this purpose. One major problem with the levels version of the Rotterdam model is that it cannot allow us to identify the impacts of household composition variables because of the existence of zero-value observations. Both models used in this study are theoretically derived. Although both models are developed to explore the role of nutrients in consumer food demand, they are different in terms of theoretical backgrounds or philosophy, and consequently, results.

In summary, this study explores the roles of nutrients in the demand for food using two different approaches. According to the results from both models, the demand for various nutrients appears to be a considerable factor in the household demand for foods. The results suggest that the system approaches used in both models are promising.

CHAPTER 5
SUMMARY AND CONCLUDING REMARKS

In this study, two different approaches, in the context of the demand subsystem, are adapted to explore the role of nutrients in consumer food demand patterns. First, a levels version of the Rotterdam model is developed through the utility theory; that is, nutrients are assumed to affect consumer's utility and, in turn, food demand. The second approach is based on the household production theory; that is, a household is assumed to purchase various food inputs in the markets to produce the utility-yielding non-market outputs, nutrients and meals.

Using data from the 1987-88 NFCS, food is classified into five groups. Three to five nutrients were examined in each food group for the levels version of the Rotterdam model, while seven nutrients in aggregated values were examined in the household production model. The food groups are dairy (milk, cheese, and yogurt); meats and other protein products (poultry, beef, pork, seafood, dry beans, and nuts); vegetables and fruit; grains (bread, pasta, rice, and cereal); and others (fats and oils, sugar and sweets, and other miscellaneous). The nutrients in these five food groups are carbohydrates; fats and oils; proteins; vitamin I (vitamins B-6 and C, thiamin, riboflavin, and niacin); vitamin II (folate and vitamin B-12); digestible fibers; and minerals (calcium, phosphorus, magnesium, iron, zinc, copper, sodium, and potassium). The estimation results from both models were reported in Chapter 4. The summary, concluding remarks, and implications of both model specifications are presented in this chapter.

Summary

The Levels Version of The Rotterdam Model

An extended levels version of the Rotterdam model was derived under the assumption that consumer's utility is a function of both nutrients and the amount of food consumed. The salient feature of this specification is that it allows nutrients to come into play so as to influence the food prices perceived by consumers and, consequently, to affect the food quantities consumed. For example, excess fats in meats may have a negative impact on the price of meat perceived by consumers.

Results show that most demand parameter estimates are significantly different from zero at $\alpha = 0.05$ level. Expenditure elasticities, price elasticities, and nutrient elasticities are consistent with expectations. The expenditure elasticity estimates indicate that the consumption of dairy and grain groups increase more than proportionally as food expenditure increases; while the consumption of meat, vegetables and fruit, and others groups increase less than proportionally. All compensated and uncompensated own-price demand elasticity estimates are negative, as expected, and elastic. According to these own-price elasticity estimates, all food groups are very sensitive to their own price changes. All compensated and uncompensated cross-price demand elasticity estimates are positive and small in magnitude compared to own-price demand elasticity estimates. The positive cross-price elasticity estimates indicate that a substitution relationship exists between any two of the food groups considered. Positive and negative own-nutrient elasticity estimates were found which might be resulted from the fact that consumers behave rationally for being nutrition-conscious. For example, a consumer eats less meats because they are rich in fats (the own-nutrient elasticity

estimate is -0.17) and more dairy products because they are rich in calcium (a kind of mineral, the own nutrient elasticity estimate for minerals is 3.32). People eats various foods at meals in which there exist complicated interrelationships of various nutrients. There are positive and negative cross-nutrient demand elasticity estimates, implying that both substitution and complementary relationships exist between nutrients. For example, a 1 percent increase in protein content in dairy products increases grain consumption by 1.12 percent, while a 1 percent increase in mineral content in meats leads to a decrease in grain consumption by 1.62 percent.

In this extended levels version of the Rotterdam model, the impact of nutrients on food consumption can be estimated indirectly through the price mechanism; that is, nutrients influence consumer's perception about food prices. The results imply that nutritional contents in meats (proteins, fats, minerals); vegetables and fruit (carbohydrates, vitamin I, vitamin II, fibers, and minerals); and grains (carbohydrates, vitamin I, vitamin II, fibers, and minerals) lower the consumer's perceived prices of these food groups, thus increasing their consumption. The nutritional contents (carbohydrates, fats and oils, and minerals) in the other group increase the consumer's perceived price of this food group, therefore decreasing their consumption. These results are consistent with consumer's rational behavior.

The Household Production Model

Two optimization problems are solved in the household production model. In the upper stage, a household was assumed to minimize its food expenditure for given levels of various nutrients and total food quantity. A translog cost function was used to characterize the household's production function how the household transforms market goods -- different

foods, into non-market goods -- nutrients and meals. In the lower stage, the household was then assumed to maximize its utility in consuming nutrients and meals subject to a food expenditure constraint. This framework allows us to not only examine the shadow prices of nutrients but also the relationship between nutrient shadow prices and the demand for nutrients directly.

The translog cost function seems to fit the data well, and the shadow prices derived from the cost function appear plausible in terms of its elasticities of substitution and factor demands. Results show that proteins have the highest shadow price, followed by fibers, vitamin I, fats and oils, carbohydrates, and minerals. A negative shadow price was found for folate and vitamin B-12 that may indicate the general public does not recognize the importance of these minerals. However, this finding is inconsistent with the findings of the levels version of the Rotterdam model. In the Rotterdam model, folate and vitamin B-12 are found to be valuable, thus decreasing the perceived prices for vegetables and fruit and grains and, consequently, increasing consumption of vegetables and fruit. The discrepancy could be attributed to the definitions of these variables in the two models. In the levels version of the Rotterdam model, nutrients are food-group specific, but in the household production model, nutrients are aggregated across all five food groups. In order to compare the results from these two models regarding this issue, more elaborate definitions of nutrients variables in the household production model are needed. However, this will increase the number of parameters tremendously, causing difficulty in the interpretation of estimates.

In the lower stage of the maximization problem, the demand for nutrients was assumed as a function of shadow prices, total food expenditure, and household composition. Results show that the own-price (shadow) elasticity estimates are negative, except those for

folate and vitamin B-12 and the number of meals eaten at home. Most cross-price elasticity estimates are negative, inelastic, and small in magnitude; expenditure elasticity estimates of carbohydrates, proteins, folate and vitamin B-12, fibers, minerals, and the number of at-home meals are inelastic; and the expenditure elasticity estimates for fats and oils and vitamin I (vitamins C and B-6, thiamin, riboflavin, and niacin) are close to one. The expenditure elasticity estimates suggest that, when at-home food expenditures increase, consumers allocate approximately an unchanged fraction of the food budget to the consumption of fats and oils and vitamin I and less to carbohydrates, proteins, vitamin II, fibers, minerals, and the number of home-prepared meals.

Given the specification of demand functions for nutrients in the lower stage of the household production model, researchers can investigate the impact of household composition variables on the consumption of nutrients. These impacts are reported in Table 4-11; most of the findings are reasonable. For example, the average weekly fat and oil intake per household decreases for the addition of a household member in age groups 1 (zero to six), 5 (46 to 60) and 6 (over 60); this finding is consistent with the fact that the older population is relatively concerned about the cholesterol levels in their blood streams and is thus cautious about fat and oil intake. The marginal weekly protein intakes will increase for all age groups as the number of group members increases; this finding is consistent with the notion that food consumption and nutrient intakes increase as the number of members in a household increases. Fibers increase with the addition of a household member in age group 5, which is a reasonable outcome. The weekly number of meals increase for all age groups considered in this study as the number of group members increases; this is also consistent with the notion that more meals will be consumed as the number of group members increases. However, the

finding that the consumption for vitamin I (vitamins C, and B-6, thiamin, riboflavin, and niacin as a group), decreases with the addition of a household member in age groups 1 and 4 (19 to 45) is a surprise.

Concluding Remarks

The findings of both approaches support the argument that nutrients play an important role in consumer's demand for food. The results show the sub-demand system approaches that were used to be promising. In the levels version of the Rotterdam model, more than half of the own-nutrient elasticities have positive signs, while in the household production model, most price-nutrient elasticities are negative. These are expected outcomes.

However, both specifications have their own shortcomings. The major problem associated with the levels version of the Rotterdam model is that the impacts of household composition can not be easily assessed because of zero-value observations. The drawback of the household production model is that the cross-effect between nutrients from different sources cannot be identified because all nutrients are aggregated across food groups. Nevertheless, this drawback can be voided in the levels version of the Rotterdam model, or a more detailed specification in the household production model can be used to solve this problem. The latter solution would lead to a dramatic increase in the number of parameters that need to be estimated and would also cause interpretation difficulties.

In order to fully understand the role of nutrients in the demand for food, more nutrients must to be included in both models. To include more nutrient variables in the analysis, it is necessary to find means by which the zero-value observation problem may be overcome. For example, the other food group used in this study is defined as the sum of three

food groups -- fats and oils, sugar and sweets, and miscellaneous -- because there are too many zero-value observations and nutrients are not consumed in the three individual categories. Statistical methods, such as the ones developed by Lee and Pitt (1986) and Wales and Woodland (1983), offer solutions to systems with specific utility functions and a limited number of demand equations. These statistical methods limit the ability for researchers who want to study the demand for the basic food groups. Until more efficient statistical methods are developed, the ability to incorporate more food groups and more nutrients in food demand analyses seem to be limited.

Implications

As mentioned in the introduction, there are many promotional activity programs in which nutritional attributes are the major theme. All these promotional activities are intended to change consumers' perceptions and awareness of nutritional contents in the food commodities in question so that they will increase their consumption of those food commodities.

With the levels version of the Rotterdam model, nutrients affect food consumption through "perceived prices." That is, "good" nutrients lower perceived price and increase the consumption of the food group in question and vice versa. According to the estimated impact of own-nutrient shown in Table 4-5, some implication can be made in addressing nutrition education and health promotion programs. For example, if the goal of a policy is to increase the consumption of vegetables and fruit, then it can be accomplished by a nutrition education program that emphasizes the importance of fibers, folate and vitamin B-12, and minerals and provides information about the nutritional contents of vegetables and fruit. Or if the goal of

a policy is to decrease the consumption of "bad" cholesterol in people's diets, then nutrition education programs can be designed to provide information such as the health risk involved with the consumption of fats and oils. Or if the goal is to increase the consumption of vegetables and fruit while at the same time decreasing meat consumption, then nutrition education can be focused on the importance of vitamin II, fibers and minerals, and the adverse health impact of fats.

On the other hand, the household production model allows us to calculate the shadow prices of nutrients. These estimates suggest that nutrients cost different prices to consumers; proteins cost the most; and minerals cost the least. These shadow price estimates can be very useful when designing food-related policy. For example, if the goal of the policy is to promote a nutritious and balanced diet, then programs designed to influence the shadow prices for nutrients may be appropriate such as nutrition education programs and promotional activity programs may be appropriate. Both types of programs provide consumers with knowledge about various nutrients that may change their perceptions of nutrients, then alter their shadow or implicit prices of nutrients, and finally change their food budget allocations for various nutrients.

Understanding the factors that influence food choices and particularly how nutrients affect them is critical to food policy. This study explores the insights of how nutrients influence food demand and suggests that both nutrition education and promotional activity programs serve as policy instruments. Food choices affect not only consumers' health but also economy, agricultural production, the balance of trade, employment in the food sector, and the success of many companies. In other words, consumers play the key role in linking the provision of food by the agricultural sector to the ultimate nutritional well-being of the

population. With the conclusion that consumers or households do consider nutritional contents as they consume food and given the fact that Americans, on the average, do not maintain healthy diets, the results from this study are useful in targeting nutrition education and health promotion activities and can provide the basis for the development of a variety of additional tools, thus promoting the nutritional well-being of the population.

REFERENCES

Adrian, J., and R. Daniel. 1976. "Impact of Socioeconomic Factors on Consumption of Selected Food Nutrients in the United States," *American Journal of Agricultural Economics*, 58 (1): 31-8.

Akin, J.S., D.K. Guilkey, and B.M. Popkin. 1983. "The School Lunch Program and Nutrient Intake: A Switching Regression Analysis," *American Journal of Agricultural Economics*, 65 (3): 477-85.

Amemiya, T. 1974. "Multivariate Regression and Simultaneous Equation Models When the Dependent Variables Are Truncated Normal," *Econometrica*, 42 (6): 999-1012.

Amemiya, T. 1985. *Advanced Econometrics*. Cambridge: Harvard University Press.

Aviphant, P., J. Lee, and M.G. Brown. 1988. "Advertising and the Demand for Fruit Juices: A Demand Subsystem Approach," a paper presented at the 1987 American Agricultural Economics Association annual meetings.

Barten, A.P. 1964a. "Consumer Demand Functions under Conditions of Almost Ideal Additive Preferences," *Econometrica*, 32 (1-2): 1 - 38.

Barten, A.P. 1964b. "Family Composition, Prices, and Expenditure Patterns," in *Econometric Analysis for National Economic Planning*, P. E. Hart, G. Mills and J. K. Whittaker (eds.), London: Butterworth, 277-92.

Barten, A.P. 1969. "Maximum Likelihood Estimation of a Complete System of Demand Equations," *European. Economic Review*, 1 (1): 7-73.

Barten, A.P. 1989. "Towards a Levels Version of the Rotterdam and Related Demand Systems," in *Contributions to Operations Research and Economics: the Twentieth anniversary of Core*, B. Cornet and H. Tulkens (eds.), Cambridge Mass.: MIT Press, 441-65.

Barten, A.P., and S.J. Turnovsky. 1966. "Some Aspects of the Aggregation Problem for Composite Demand Equations." *International Economic Review* 7 (3): 231-59.

Basiotis, P., M. Brown, S.R. Johnson, and K.J. Morgan. 1983. "Nutrient Availability, Food Costs, and Food Stamps," *American Journal of Agricultural Economics*, 65 (4): 685-93.

Basmann, R.L. 1956. "A Theory of Demand with Variable Consumer Preferences," *Econometrica*, 24 (1): 47-58.

Becker, G.S. 1965. "A Theory of the Allocation of Time," *Economics* Journal, 75 (299): 493-517.

Bewley, R. 1986. *Allocation Models*. Massachusetts: Ballinger.

Binswanger, H.P. 1974. "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution," *American Journal of Agricultural Economics*, 56 (2): 377-86.

Birch, L.L., J. Billman, and S.S. Richards. 1984. "Time of Day Influences Food Acceptability," *Appetite*, 5 (2): 109-116.

Blundell, R. and C. Meghir. 1987. "Bivariate Alternatives to the Tobit Model," *Journal of Econometrics*, 34 (2): 179-200.

Borra, S.T. 1988. "A Healthy Diet with Animal Product Options: What the Food Marketer and Consumer are Doing." Food Marketing Institute, Washington D.C.

Branson, R.E., H.R. Cross, J.W. Savell, G.C. Smith, and R.A. Edwards. 1986. "Marketing Implications from the National Consumer Beef Study," *Western Journal of Agricultural Economics*, 11 (1): 82-91.

Breidenstein, B.C. 1988. "Changes in Consumer Attitudes Toward Red Meat and Their Effect on Marketing Strategy," *Food Technology* 42 (1): 112.

Brown, M. 1994. "Levels Versions of the Rotterdam Demand Model and Incorporation of Demographic, Stock and Other Nonprice, Nonincome Variables,." *Canadian Journal of Agricultural Economics*, 42 (3): 355-66.

Brown, D.J., and L.F. Schrader. 1990. "Cholesterol Information and Shell Egg Consumption," *American Journal of Agricultural Economics*, 72 (3):548-55.

Bull, N. 1985. "Dietary Methods of 15 to 25 Years Olds," Supplement 1 to *Human Nutrition, Applied Nutrition*, 39a:1-68.

Capps, O., Jr. 1987. "Price and Quality Effects in Cross-Sectional Demand Analysis: Comment." Tech. Article No. 22840, Texas Agricultural Experiment Station, Texas A&M Univ.

Capps, O., Jr., D.S. Moen, and R.E. Branson. 1988. "Consumer Characteristics Associated with Selection of Lean Meat Products," *Agribusiness*, 4 (6): 549-57.

Capps, O., Jr., and J.D. Schmitz. 1991. "A Recognition of Health and Nutrition Factors in Food Demand Analysis," *Western Journal Agricultural Economics*, 16 (1): 21-35.

Carlin, P.S. 1991. " Intra-family Bargaining and Time Allocation," in *Research in Population Economics* 7, A Research Annual, Schultz T. P. (ed.), Greenwich, Conn. & London: JAI Press: 215-43.

Carruthers, F. 1988. *Grazing in Peckham*. London Food Commission Report, London.

Chang, H.S., and H. Kinnucan. 1991. "Advertising, Information, and Product Quality: The Case of Butter," *American Journal of Agricultural Economics*, 73 (4): 1195-1203.

Chavas, J.P., and K.O. Keplinger. 1983. "Impact of Domestic Food Programs on Nutrient Intake of Low Income Persons in the United States," *Southern Journal Agricultural Economics*, 15 (1):155-63.

Cleveland, L.B., A.B. Peterkin, and S. Becker. 1983. "Recommended Dietary Allowances as Standards for Family Food Plans," *Journal of Nutrition Education*, 15 (1): 8-14.

Cook, C.M., and D.B. Eastwood. 1992. "Incorporating Subsistence into Hedonic Price and Nutrient Demand Equations," *Journal of Consumer Affairs* 26 (2): 288-304.

Datcher-Loury, L. 1988. "Effects of Mother's Home Time on Children's Schooling," *Review of Economics and Statistics*, 70 (3): 367-73.

deCastro, J.M., and E.S. deCastro. 1989. "Spontaneous Meal Patterns of Human: Influence of the Presence of Other People," *American Journal of Clinical Nutrition*, 50 (3): 237-247.

Deaton, A., and M. Irish. 1984. "Statistical Models for Zero Expenditures in Households Budgets," *Journal of Public Economics*, 23 (1-2): 59-80.

Deaton, A., and J. Muellbauer. 1980. *Economics and Consumer Behavior*. Cambridge: Cambridge University Press.

Decision center, Inc. 1987. *Giant Lean Awareness and Usage*. Res. Rep.to the Center for Meat Marketing Research American Meat Institute.

Devaney, B., and T. Fraker. 1989. "The Dietary Impact of the School Breakfast Program," *American Journal of Agricultural Economics*, 71 (4): 932-48.

Duffy, M. 1987. "Advertising and the Inter-product Distribution of Demand: A Rotterdam Model Approach," *European Economic Review*, 31 (5): 1051 - 70.

Duffy, M. 1989. "Measuring the Contribution of Advertising to Growth in Demand: An Econometric-accounting Framework," *International Journal of Advertising* 8 (1): 95-110.

Eastwood, D.B., J.R. Brooker, and D.E. Terry. 1986. "Household Nutrient Demand: Use of Characteristics Theory and a Common Attribute Model," *Southern Journal of Agricultural Economics,* 18 (2): 235-46.

FASEB (Federation of American Societies for Experimental Biology). 1991. "Impact of Nonresponse on Dietary Data from the 1987-88 Nationwide Food Consumption Survey." Bethesda, Maryland: Life Sciences Research Office.

Frisch, R. 1959. "A Complete Scheme for Computing all Direct and Cross Demand Elasticities in a Model with Many Sector," *Econometrica*, 27 (2): 177-96.

Geary, P.T., and M. Morishima. 1973. "Demand and Supply under Separability," in *Theory of Demand, Real and Monetary*, M. Morishima (ed.), Oxford: Oxford University Press, 87-147.

General Accounting Office (GAO). 1991. "Nutrition Monitoring, Mismanagement of Nutrition Survey Has Resulted in Questionable Data," *RCED*-91-117.

Goldman, S.M., and H. Uzawa. 1964. "A Note on Separability in Demand Analysis," *Econometrica*, 32 (3): 387-98.

Gorman, W.M. 1956. "A Possible Procedure for Analyzing quality differentials in the Egg Market," Ames: Iowa State College, mimeo. (Reprinted in the *Review of Economic Studies*, 47: 843-56, 1980.)

Gorman, W.M. 1959. "Separable Utility and Aggregation," *Econometrica*, 27 (3): 469-81.

Gorman, W.M. 1968. "Conditions for Additive Separability," *Econometrica*, 36 (3-4): 605-09.

Gould, B.W., T.L. Cox, and F. Perali. 1991. "Demand for Food Fats and Oils: The Role of Demographic Variables and Government Donations," *American Journal of Agricultural Economics*, 73 (1): 212-21.

Gronau, R. 1970. "The Value of Time in Passenger Transportation: The Demand for Air Travel," *Occasional Paper* No. 109. NY:NBER.

Heckman, J. 1978. "Dummy Endogenous Variables in a Simultaneous Equation System," *Econometrica*, 46 (6): 931-959.

Heien, D., and C.R. Wessells. 1990. "Demand Systems Estimation With Microdata: A Censored Regression Approach," *Journal of Business & Economic Statistics*, 3 (8): 365-371.

Hill, C.R., and F.P. Stafford. 1985. "Parental Care of Children: Time Diary Estimates of Quantity, Predictability and Variety," in *Time, Goods, and Well-being*, F.T. Juster and F.P. Stafford (eds.), Ann Arbor, Michigan: Institute for Social Research, University of Michigan.

Hill, M., and F.T. Juster. 1985. "Constraints and Complementaries in Time Use," in *Time, Goods, and Well-being*, F.T. Juster and F.P. Stafford (eds.), Ann Arbor, Michigan: Institute for Social Research, University of Michigan.

Houthakker, H.S., 1954. "La Forme des Courbes d'Engel," *Cahiers du Seminaire d'Econometrie*, 2 (1): 59-66.

Huang, K.S. 1996. "Nutrient Elasticities in a Complete Food Demand System," *American Journal of Agricultural Economics*, 78 (1): 21-9.

Huffman, J.A. 1988. "The Influence of income and Demographic Variables on American Households' Achievement of Nutritionally Adequate Diets." Ph. D. dissertation, Univ. Of California, Davis.

Juster, F.T. 1985. "Preferences for Work and Leisure," in *Time, Goods, and Well-being*, F.T. Juster and F.P. Stafford (eds.), Ann Arbor, Michigan: Institute for Social Research, University of Michigan.

Kare, M.R., and O. Maller (eds.) 1967. *The Chemical Senses and Nutrition*. Baltimore: John Hopkins Press.

Kare, M.R., and O. Maller (eds.) 1977. *The Chemical Senses and Nutrition*. New York: Academic Press.

Kay, J.A., M.J. Keen, and C.N. Morris. 1984. "Estimating Consumption From Expenditure Data," *Journal of Public Economic*, 23 (1/2): 169-82.

Keen, M. 1986. "Zero Expenditures and the Estimation of Engel Curve," *Journal of Applied Econometrics*, 1(3): 277-286.

Kmenta, J. 1971. *Elements of Econometrics*. New York: Macmillan.

Kmenta, J., and R.F. Gilbert. 1968. "Small Sample Properties of Alternative Estimates of Seemingly Unrelated Regressions," *Journal American Statistics Association* 63 (6): 1180-1200.

Kuhn, H,W., and A.W. Tucker. 1951. "Nonlinear Programming," in *Proceedings of the second Berkeley Symposium on Mathematical Statistics and Probability*, J. Neyman (ed.), Berkeley, CA: University of California Press.

Lancaster, K.J. 1966. "A New Approach to Consumer Theory," *Journal of Political Economy,* 74 (2): 132-57.

Lancaster, K.J. 1971. *Consumer Demand: A New Approach.* New York: Columbia University Press.

Ladd, G.W., and V. Suvannunt. 1976. "A Model of Consumer Goods Characteristics," *American Journal of Agricultural Economics*, 58 (3): 504-10.

LaFrance, J.T. 1983. "The Economic of Nutrient Content and Consumer Demand for Food." Ph. D. Dissertation, Univ. Of California, Berkeley.

Lee, L.F. 1978. "Simultaneous Equations Models With Discrete and Censored Dependent Variables," in *Structure Analysis of Discrete Data With Econometrics Application*, P. Manski and D. McFadden (eds.), Cambridge, MA: MIT Press, pp. 346-364.

Lee, L.F. and M.M. Pitt. 1984. "Microeconometric Models of Consumer and Producer Demand With Limited Dependent Variables," *Discussion Paper*, Department of Economics, University of Minnesota.

Lee, L.F. and M.M. Pitt. 1986 "Microeconometric Models of Rationing, Imperfect Markets, and Non-negativity Constraints," *Journal of Econometrics*, 36 (1/2): 89-110.

Leontief, W.W. 1947. "A Note on the Interrelation of Subsets of Independent Variables of a Continuous Function with Continuous first Derivatives." *Bulletin of the American Mathematical Society*, 53 (6): 343-50.

Louis Harris & Associates, Inc. 1993. "Trends - Consumer Attitudes and the Supermarket." Food Marketing Institute, Washington D. C.

McElroy, M.B., and M.J. Horney. 1981. "Nash Bargained Household Decisions," *International Economic Review*, 22 (2): 333-49.

McNutt, K.W., M.E., Powers, and A.E., Sloan. 1986. "Food Colors, Flavors, and Safety: A Consumer Viewpoint," *Food Technology*, 40 (January): 72-78.

Manderscheid, L.V. 1964. "Some Observations on Interpreting Measured Demand Elasticities," *Journal of Farm Economics*, 46 (1): 128-36.

Manser, M., and M. Brown. 1980. "Marriage and Household Decision Making: A Bargaining Analysis," *International Economic Review*, 21 (1):31-44.

Meiselman, H.L. 1992. "Methodology and Theory in Human Research," *Appetite*, 19 (1): 49-55.

Meiselman, H.L., E.S. Hirsch, and R.D. Popper. 1988. "Sensory, Hedonic, and Situational Factors in Food Acceptance and Consumption ," in *Food Acceptability*, D.M.H. Thomson (ed.). London: Elsevier, 77-78.

Mendelsohn, R. 1984. "Estimating the Structural Equations of Implicit Markets and Household Production Functions," *Review of Economics and Statistics*, 66 (4): 673-77.

Menkhaus, D.J., G.D. Whipple, S.J. Torok, and R.A. Field. 1988. "Developing a Marketing Strategy for Branded, Low Fat, Fresh Beef," *Agribusiness*, 4 (1): 91-103.

Michael, R.T., and G.S. Becker. 1973. "On the New Theory of Consumer Behavior," *Swedish Journal of Economics*, 75 (4)78-96.

Mincer, J. 1962. "Labor Force Participation of Married Women," in *Aspects of Labor Economics*. Universities-National Bureau Conference Series No. 14. NY: NBER, pp. 63-105.

Morgan, K.J., E.J. Metzen, and S.R. Johnson. 1979. "A Hedonic Index of Breakfast Cereals," *Journal of Consumer Research*, 6 (1): 67-75.

Murphy, S.P., D. Rose, M. Hudes, and F.E. Viteri. 1992. "Demographic and Economic Factors Associated With Dietary Quality for Adults in the 1987-88 Nationwide Food Consumption Survey," *Journal of American Dietetic Association*, 92 (7): 1352-57.

Nelson, F.D., and L. Olson. 1978. "Specifications and Estimation of a Simultaneous Equation Model With Limited Dependent Variables," *International Economic Review*, 19 (3): 695-710.

Oberhofer, W., and J. Kmenta. 1974. "A General Procedure for Obtaining Maximum Likelihood Estimates in Generalized Regression Models," *Econometrica*, 42 (3): 579-90.

Pelto, G.H. 1981. "Anthropological Contributions to Nutrition Education Research," *Journal of Nutrition Education*, 13 (suppl.): S2-S8.

Phlips, L. 1974. *Applied Consumption Analysis*. New York: North Holland.

Pinstrup-Anderson, P., and E. Caicedo. 1978. "The Potential Impact of Changes in Income Distribution on Food Demand and Human Nutrition," *American Journal of Agricultural Economics*, 60 (3): 402-12.

Pitt, M.M. 1983. "Food Preferences and Nutrition in Rural Bangladesh," *Review of Economics and Statistics*, 65 (1): 105-14.

Pulter, D.S. 1987. "The Effect of Health Information on Shell Egg Consumption." Working Paper, Univ. Of California, Davis.

Putnam, J.J. 1990. "Food Consumption, Prices and Expenditure 1967-88," *Statistical Bulletin*, 804, Res. Services, U.S. Department of Agriculture, Washington, DC.

Raats, M., B. Daillant-Spinnler, R. Deliza, and H. MacFie. 1995. "Are Sensory Properties Relevant to Consumer Food Choice?" in *Food Choice and the Consumer*, D.W. Marshall (ed.), Glasgow: Blackie Academic & Professional, 239-63.

Ransom, M.R. 1987. "A Comment on Consumer Demand System With Binding Non-negativity Constraints," *Journal of Econometrics*, 34 (4): 355-359.

Rogers, B.L., and F.J. Levinson. 1976. "Subsidized Food Consumption System in Low Income Countries: The Pakistan Experience." *International Nutrition Program Discussion Paper* 76-1, MIT.

Rozin, P., and H. Tuorila. 1993. "Simultaneous and Temporal Contextual Influences on Food Acceptance," *Food Quality and Preference*, 4 (1): 11-20.

Sahn, D.E. 1988. "The Effect of Price and Income Changes on Food-Energy Intake in Sri Lanka," *Economics Development And Culture Change*, 36 (2): 315-40.

Scearce, W.K., and R.B. Jensen. 1979. "Food Stamp Program Effects on Availability of Food Nutrient s for Low Income Families in the Southern Region of the United States," *Southern Journal of Agricultural Economics*, 11 (2): 113-20.

Schafer, R.B. 1978. "Factors Affecting Food Behavior and the Quality of Husbands' and Wives' Diets," *Journal of the American Dietetic Association*, 72 (February): 138-143.

Schmidt, P. 1976. *Econometrics*. New York: Dekker.

Schutz, H.G., D.S. Judge, and J. Gentry. 1986. "The Importance of Nutrition, Brand, Cost, and Sensory Attributes to Food Purchase and Consumption," *Food Technology*, 40 (11): 79-82.

Selvanathan, E.A. (1989) "Advertising and Consumer Demand: A Differential Approach," *Economics Letters*, 31 (3): 215-9.

Senauer, A., E. Asp, and J. Kinsey. 1991. *Food Trends and the Changing Consumers*. Minnesota: Egan Press.

Skaggs, R.K., D.J. Menkhaus, S.J. Torok, and R.A. Field. 1987. "Test Marketing of Branded, Low Fat, Fresh Beef," *Agribusiness* 3(3): 257-71.

Sono, M. 1961. "The Effect of Price Changes on the Demand and Supply of Separable Goods," *International Economic Review*, 2 (3): 239-71.

Stafford, F.P. 1987. "Women's Work, Sibling, Competition, and Children's School Performance," *American Economic Review*, 77 (5): 972-80.

Stigler, G.L., and G.S. Becker. 1977. "De Gustibus Non Est Disputandum," *American Economic Review*, 67 (2): 76-90.

Stokes, R.C., and F. Haddock. 1972. "Interim Report of the First Two Phases of the FDA Nutritional Labeling Research Program." Working Paper, Consumer Research Institute, Washington, D. C.

Stone, R. 1954. "Linear Expenditure System and Demand Analysis: An Application to the Pattern of British Demand," *Economics Journal*, 64 (255): 511-27.

Strotz, R.H. 1957. "The Empirical Implications of a Utility Tree," *Econometrica*, 25 (1): 269-80.

Strotz, R.H. 1959. "The Utility Tree-a Correction and Further Appraisal," *Econometrica*, 27 (3): 482-88.

Swartz, D.G., and I.E. Strand, Jr. 1981. "Avoidance Costs Associated with Imperfect Information: The Case of Keptone," *Land Economics*, 57 (1): 139-50.

Theil, H. 1965. "The Information Approach to Demand Analysis," *Econometrica*, 33 (1): 67-87.

Theil, H. 1971. *Principles of Econometrics*. New York: Willey.

Theil, H. 1976. *Theory and Measurement of Consumer Demand*, Vol II. Amsterdam: North Holland.

Theil, H. 1980 *The System-Wide Approach to Microeconomics*, Chicago: The University of Chicago Press.

Timmer, C.P., and H. Alderman. 1979. "Estimating Consumption Parameters for Food Policy Analysis," *American Journal of Agricultural Economics*, 61 (5): 982-7.

Tobin, J. 1958. "Estimation of Relationships for Limited Dependent Variables," *Econometrica*, 26 (1): 24-36.

U. S. Department of Agriculture, Human Nutrition Information Service. 1991. "Evaluation of Nonresponse in the Nationwide Food Consumption Survey 1987-88." NFCS Report No. 87-M-2, Washington D.C.

U. S. Department of Agriculture, Department of Human Nutrition Information Service. 1992. "The Food Guide Pyramid." Home and Garden Bulletin No. 252, Washington, D. C.

U. S. Department of Agriculture, Center for Nutrition Policy and Promotion. 1995. "The Healthy Eating Index." CNPP-1, Washington, D.C.

U. S. Department of Agriculture, Department of Health and Human Services. 1995. "Nutrition and Your Health: Dietary Guidelines for Americans." Home and Garden Bulletin No. 232, Washington, D.C.

U. S. Department of Agriculture, Economic Research Service. 1997. "Food Consumption, Prices, and Expenditures, 1970-95." (updated 8/97). Statistical Bulletin Number 939, Washington, D.C.

University of Florida. Shands Teaching Hospital & Clinics. 1971. "Diet Manual." J. Hillis Miller Health Center, Gainesville, Florida.

Uzawa, H. 1962. "Production Functions with Constant Elasticity of Substitution," *Review Economics Studies*, 29 (81): 291-99.

Wales, T.J. and A.D. Woodland (1983) "Estimation of Consumer Demand Systems with Binding Non-Negativity Constraints," *Journal of Econometrics*, 21 (3): 263-85.

Yankelovich, Skelly, and White, Inc. 1985. *The Consumer Climate for Red Meat.* Report to the American Meat Institute and National Livestock and Meat Board.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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